BLM LIBRARY
88079836

MONITORING AND MODELING OF SHALLOW GROUNDWATER SYSTEMS IN THE POWDER RIVER BASIN

SECOND ANNUAL TECHNICAL REPORT

H-D0166-78-757F

BLM Library
Denver Federal Center
Bldg. 50, OC-521
P.O. Box 25047
Denver, CO 80225

HITTMAN
Hittman Associates, Inc.

#1382338969
ID: 88079836
GB
705
.W4
M66
1979

MONITORING AND MODELING OF SHALLOW GROUNDWATER SYSTEMS IN THE POWDER RIVER BASIN

SECOND ANNUAL TECHNICAL REPORT

H-D0166-78-757F

BLM Library
Denver Federal Center
Bldg. 50, OC-521
P.O. Box 25047
Denver, CO 80225

February 1979

Prepared Under:
U.S. Bureau of Mines
Contract No. J0265050

HITTMAN ASSOCIATES, INC.
Englewood, Colorado

NOTICE

This report was prepared as an account of work sponsored by the U.S. Bureau of Mines. Neither the United States nor the U.S. Bureau of Mines nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

TABLE OF CONTENTS

Page

NOTICE.................................... ii

TABLE OF CONTENTS......................... iii

LIST OF FIGURES........................... vi

LIST OF TABLES............................ viii

I. INTRODUCTION........................... I-1

  A. Project Background................... I-1

  B. Project Status....................... I-1

II. PERIODIC MONITORING PROGRAM............ II-1

  A. Monitoring Network................... II-1

  B. Water Level Monitoring............... II-1

  C. Water Quality Monitoring............. II-9

  D. Quality Assurance.................... II-18

III. ACQUISITION OF PUBLISHED AND UNPUBLISHED DATA...................... III-1

IV. DETERMINATION OF AQUIFER CHARACTERISTICS.. IV-1

  A. Background........................... IV-1

  B. Hanic Long Term Test................. IV-1

  C. Recovery Tests on Monitoring Wells... IV-13

V. GROUNDWATER MODELING................... V-1

  A. Flow Model........................... V-1

TABLE OF CONTENTS (Continued)

Page

B. Quality Model........................ V-8

C. Model Verification.................. V-14

VI. SURFACE WATER MODELING................... VI-1

A. Introduction........................ VI-1

B. Literature Review................... VI-1

C. Selection of a Surface Water Model... VI-3

D. Data Collection..................... VI-20

VII. PLANNED RESEARCH......................... VII-1

A. Monitoring.......................... VII-1

B. Data Collection..................... VII-1

C. Modeling............................ VII-2

VIII. REFERENCES.............................. VIII-1

APPENDIX A - GROUNDWATER MONITORING PROCEDURES AND EQUIPMENT MAINTENANCE........... A-1

APPENDIX B - MONTHLY MONITORING DATA............. B-1

APPENDIX C - LABORATORY ANALYTICAL PROCEDURES..... C-1

APPENDIX D - TRIANNUAL GROUNDWATER QUALITY DATA... D-1

APPENDIX E - QUALITY ASSURANCE PROGRAM FOR THE HITTMAN ENVIRONMENTAL CHEMICAL LABORATORY........................... E-1

TABLE OF CONTENTS (Continued)

Page

APPENDIX F - FORTRAN CODE FOR WATER QUALITY DATA CHECKING PROGRAM................ F-1

APPENDIX G - AQUIFER TEST ANALYSIS TECHNIQUES..... G-1

APPENDIX H - GROUNDWATER FLOW MODEL.............. H-1

APPENDIX I - GROUNDWATER QUALITY MODEL........... I-1

APPENDIX J - SURFACE WATER BIBLIOGRAPHY.......... J-1

APPENDIX K - ADDITIONAL PUMPING TEST SITES........ K-1

HITTMAN

LIST OF FIGURES

No.	Title	Page
II-1	Hittman Associates' Monitoring Well Network	II-2
II-2	Monthly Water Levels in Well No. 12	II-4
II-3	Monthly Water Levels in Well No. 19e	II-5
II-4	Monthly Water Levels in Well No. 44	II-6
II-5	Average Depth to Water in Observation Wells	II-7
II-6	Computer-Generated Contour Map of Average Groundwater Elevation in Powder River Basin Based on Data from Monthly Monitoring Program	II-10
II-7	Monthly Conductivity in Well No. 12	II-12
II-8	Monthly Conductivity in Well No. 19e	II-13
II-9	Monthly Conductivity in Well No. 44	II-14
IV-1	Mobile Aquifer Test Trailer	IV-2
IV-2	Layout of Hanic Pumping Test Site	IV-3
IV-3	Drawdown Versus Time for Well 19d	IV-9
IV-4	Drawdown Versus Time for Well 19e	IV-10
IV-5	Drawdown Versus Time for Pumped Well (19a)	IV-11
IV-6	Aquifer Transmissivity in the Powder River Basin	IV-15
V-1	Contour Map of Water Elevations in Wells Between 480 and 1020 Feet Deep in Powder River Basin	V-4

LIST OF FIGURES (Continued)

No.	Title	Page
V-2	Location of Data Points Used to Construct Figure V-1......................	V-5
V-3	Assumed Relationship between Transpiration and Depth..................	V-9
V-4	Hypothetical Case for a Theoretical Verification of the Model...............	V-15
V-5	Theoretical and Model Drawdowns.........	V-16
V-6	Theoretical and Model Concentrations of Pollutant Entering the Pumped Well.....	V-18
V-7	Model versus Smoothed Theoretical Results for Convection and Dispersion Example................................	V-20
V-8	Model versus Theoretical Results for High Dispersion and Different Numbers of Particles.............................	V-21
V-9	Theoretical versus Smoothed Model Results with Decay Added................	V-22
VI-1	Complete Hydrologic Simulation Framework..	VI-2
VI-2	Flow Diagram for the ARS USDAHL-75 Model (Ref. 9)..................................	VI-6
VI-3	Flow Diagram of the Hydrologic Simulation Portion of the ARM Model (Ref. 10).................................	VI-14
VI-4	First Watershed Selected for Surface Water Model Calibration and Verification..	VI-23

LIST OF TABLES

No.	Title	Page
II-1	Monthly Groundwater Observation Wells in the Present Monitoring Program..............................	II-3
II-2	Westmoreland Resources Wells.............	II-8
II-3	Ranges of Field-Measured Water Quality Parameters........................	II-11
II-4	Laboratory Analytical Procedures.........	II-16
II-5	Quality Control Test Results.............	II-20
II-6	Results of Duplicate Analyses - May, 1978................................	II-22
II-7	Results of Duplicate Analyses - September, 1978..........................	II-23
II-8	Reference Sample Analysis................	II-25
III-1	Sources for Published and Unpublished Data in the Computer Databank............	III-2
IV-1	Pumping Test Water Level Measuring Schedule..................................	IV-5
IV-2	Water Quality Parameters Measured During Long Term Pumping Test...........	IV-6
IV-3	Detailed Water Quality Analyses from Samples Taken During Pumping Test.........	IV-7
VI-1	Description of the ARS Model Subprograms.............................	VI-5
VI-2	Required Input Data for ARS USDAHL-75 Input Parameters.......................	VI-10
VI-3	Description of ARM Model Subroutines.....	VI-13
VI-4	ARM Model Input Parameters...............	VI-16

I. INTRODUCTION

A. Project Background

This project was initiated in July 1976, to determine what effects the surface mining of coal would have on the regional shallow groundwater systems in a semiarid western region. The Powder River Structural Basin of Montana and Wyoming was chosen as the study area for the project since it typifies the western semiarid climate, and large scale surface coal mining operations are present in the area. Also, these mining operations are expected to increase dramatically in the future in the Powder River Basin.

The overall project includes the following:

- Design and establishment of a regional network for monitoring the shallow groundwater systems in the Powder River Basin.
- Monitoring of the direction and rate of flow, water quality, and aquifer characteristics of the shallow groundwater systems in the basin, and monitoring of pertinent meteorological and surface water parameters.
- Collection and analysis of published and unpublished data on ground and surface water characteristics, flow, and quality in the basin; and other parameters affecting these terms.
- Development of linked regional ground and surface water simulation models, with appurtenant subroutines to determine local effects, which are capable of predicting the impacts of coal strip mining on the shallow groundwater and the surface water systems in the basin.

B. Project Status

The overall project is divided into two phases. During the six-month Phase I, an initial literature and data search was conducted, and a shallow groundwater monitoring program for the Powder River Basin was designed. The monitoring program was designed to provide sufficient data for development of the computer model. In addition, a preliminary model was developed and run during Phase I to test overall response times, sensitivity of parameters, and general model operational problems; and to identify critical elements of the groundwater monitoring program. Phase I was completed with the preparation of the Phase I Report (Ref. 1) in January 1977.

Phase II, consisting of installation and operation of the monitoring system, collection of data, and detailed development of the groundwater computer program, began in February 1977. During approximately the first six months of Phase II, the groundwater monitoring system was set-up in the Powder River Basin. Intensive monitoring began in September 1977. A report on the first year's monitoring and modeling activities under Phase II was prepared and forwarded to the U.S. Bureau of Mines in February 1978 (Ref. 2).

In October 1978, the project scope was increased to include the development of a surface water flow and quality routing model in conjunction with the groundwater model. The resulting combined model would provide a comprehensive hydrologic simulation of the Powder River Basin.

This report covers the progress on the monitoring and modeling efforts during the past year and includes tabulations of the monitoring data collected to date. Included herein are discussions of the periodic monitoring program, published data collected, aquifer characteristics evaluation program, ground and surface water modeling efforts, and research plans for the next year.

II. PERIODIC MONITORING PROGRAM

A. Monitoring Network

A total of 118 wells are presently being monitored on a monthly basis by Hittman Associates. The locations of these wells are shown by well number on Figure II-1. These wells are being monitored for water level, temperature, specific conductivity, pH, and alkalinity. In addition, monthly monitoring data from 40 observation wells is also being obtained from several coal companies in Montana and Wyoming. The total number of observation wells for which monthly data is being obtained is listed by source in Table II-1.

B. Water Level Monitoring

The procedures that Hittman Associates are currently using are detailed in Appendix A. These procedures are based primarily on in-field experience with measuring water levels. While they may differ slightly from published procedures by the U.S. Geological Survey or the Environmental Protection Agency, the procedures in Appendix A have resulted in the collection of accurate and consistent water level data under a wide range of field conditions in the Powder River Basin.

Currently, over one year of data is available for analysis. No definite, overall conclusions can yet be made about fluctuations in water levels over the entire study area. Some of the wells have had relatively constant static water levels (Figure II-2). Other wells have appeared to fluctuate on a seasonal basis (Figure II-3). In still other wells, the static water level has been steadily rising (Figure II-4) since the monitoring program began. In no instance has the water level been steadily falling in a well for which one year of data is available. The average depth to water and the surface elevation of the wells are shown in Figure II-5. The elevations and depths to water for the wells at Westmoreland Resources (Well Group No. 25) are listed in Table II-2.

A computer-generated contour map has been made of the groundwater elevations in the Powder River Basin based only on the monthly water level data collected. This map

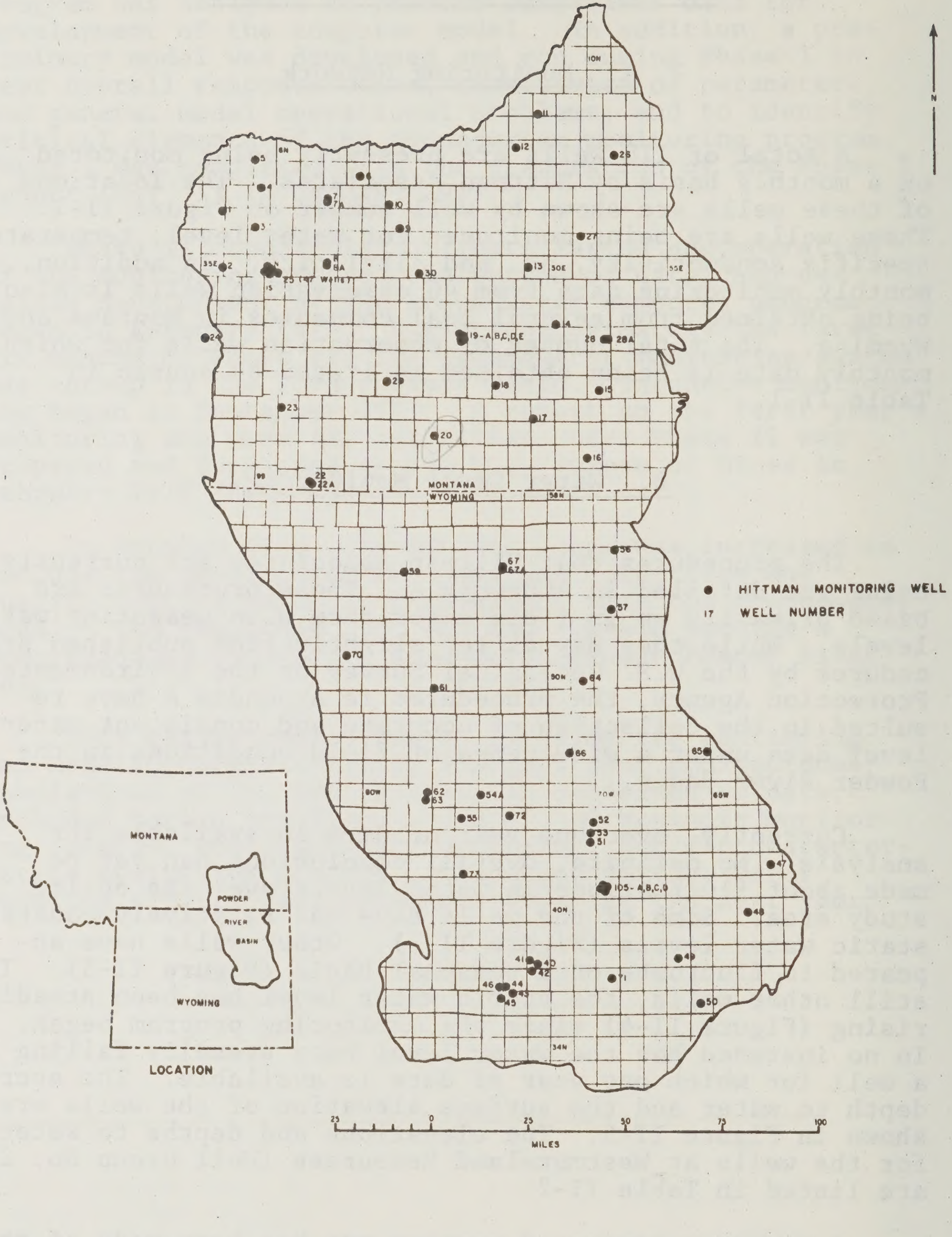

N
● HITTMAN MONITORING WELL
17 WELL NUMBER
MONTANA
WYOMING
POWDER
RIVER
BASIN
LOCATION
25 0 25 50 75 100
MILES

Figure II-1. Hittman Associates' Monitoring Well Network

TABLE II-1. MONTHLY GROUNDWATER OBSERVATION WELLS IN THE PRESENT MONITORING PROGRAM

	WYOMING WELLS	MONTANA WELLS
Private	32	31
Coal Company	20	67
Pumping Test	3	5
	55	103

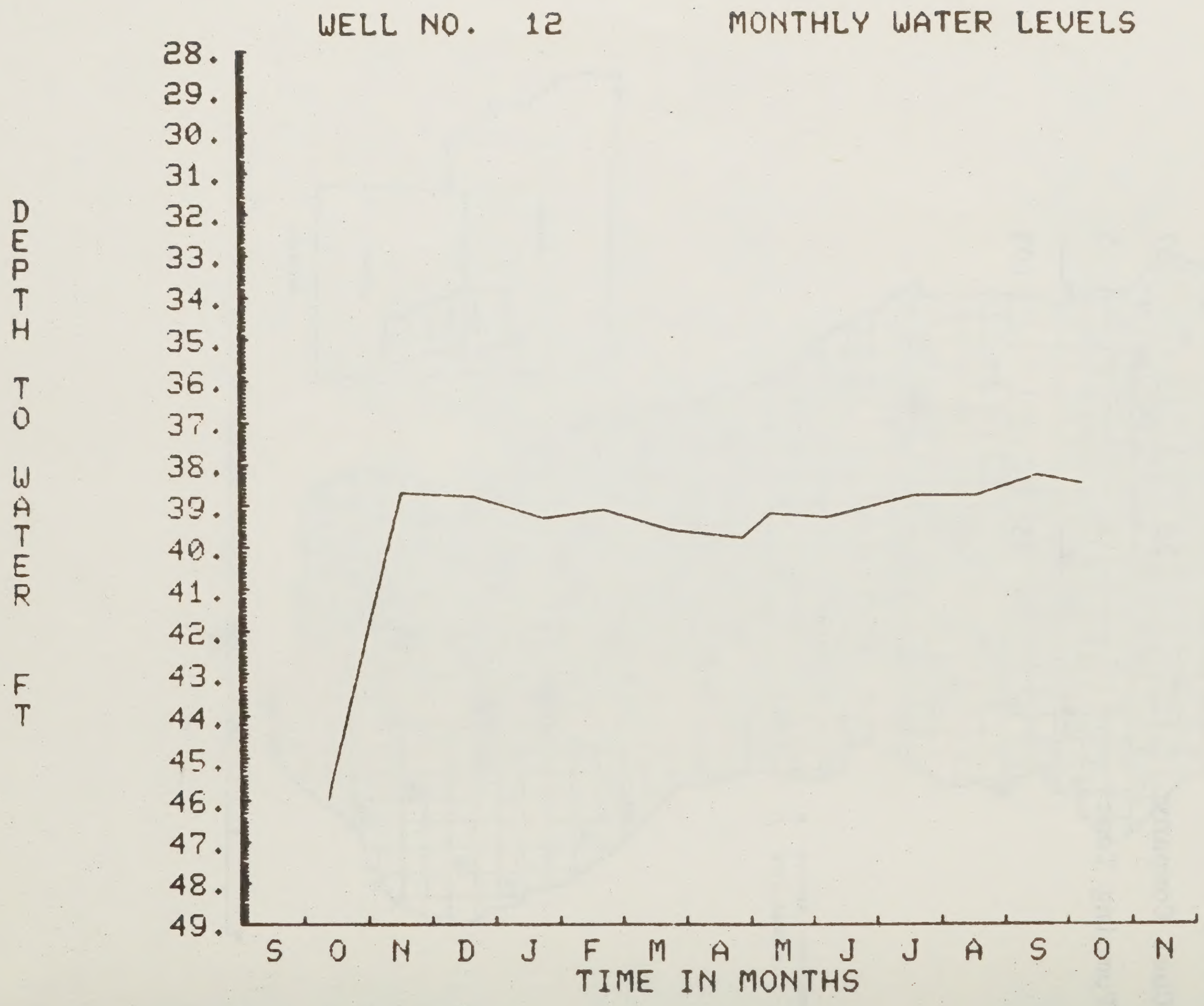


Figure II-2. Monthly Water Levels in Well No. 12

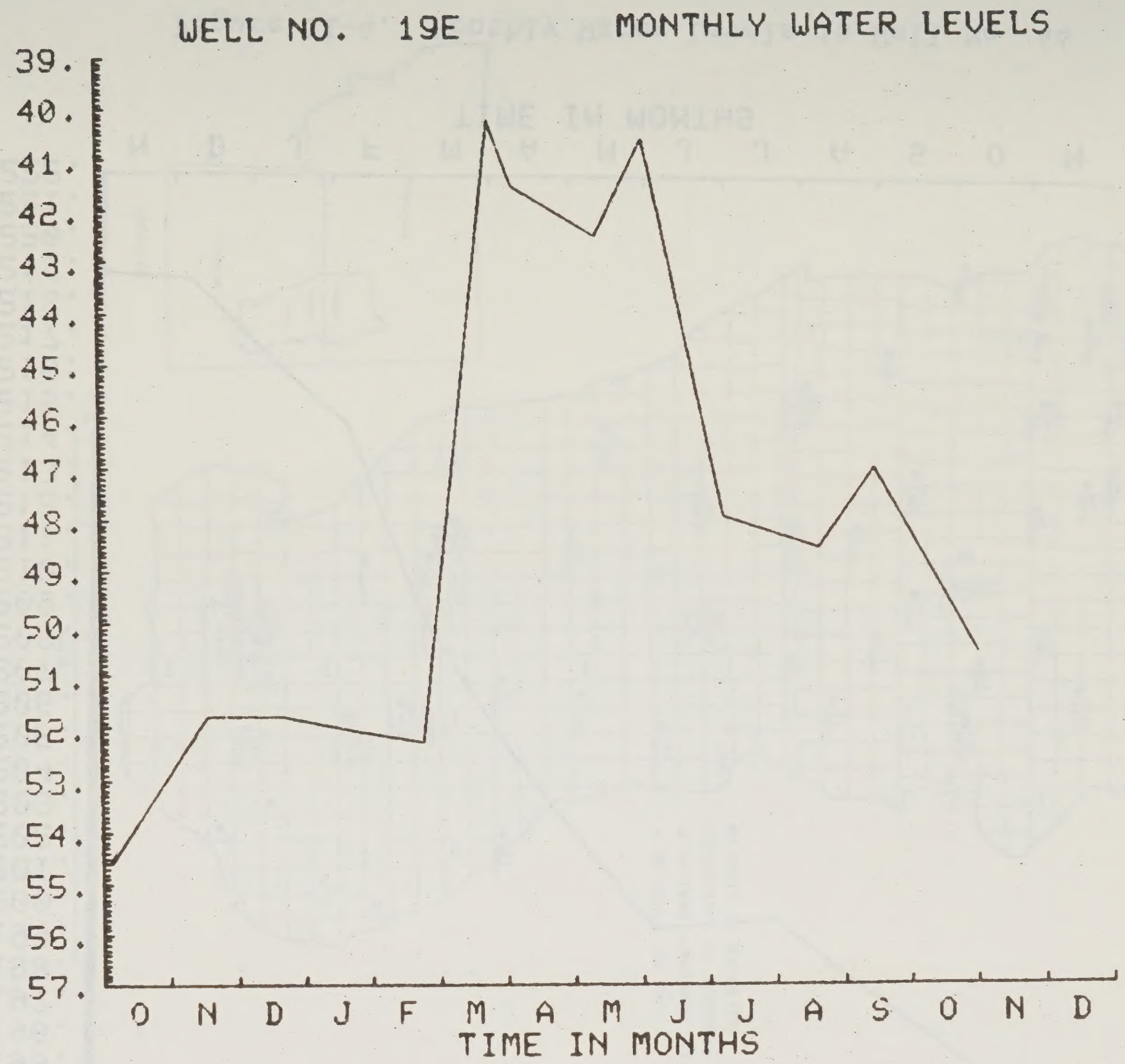


Figure II-3. Monthly Water Levels in Well No. 19e

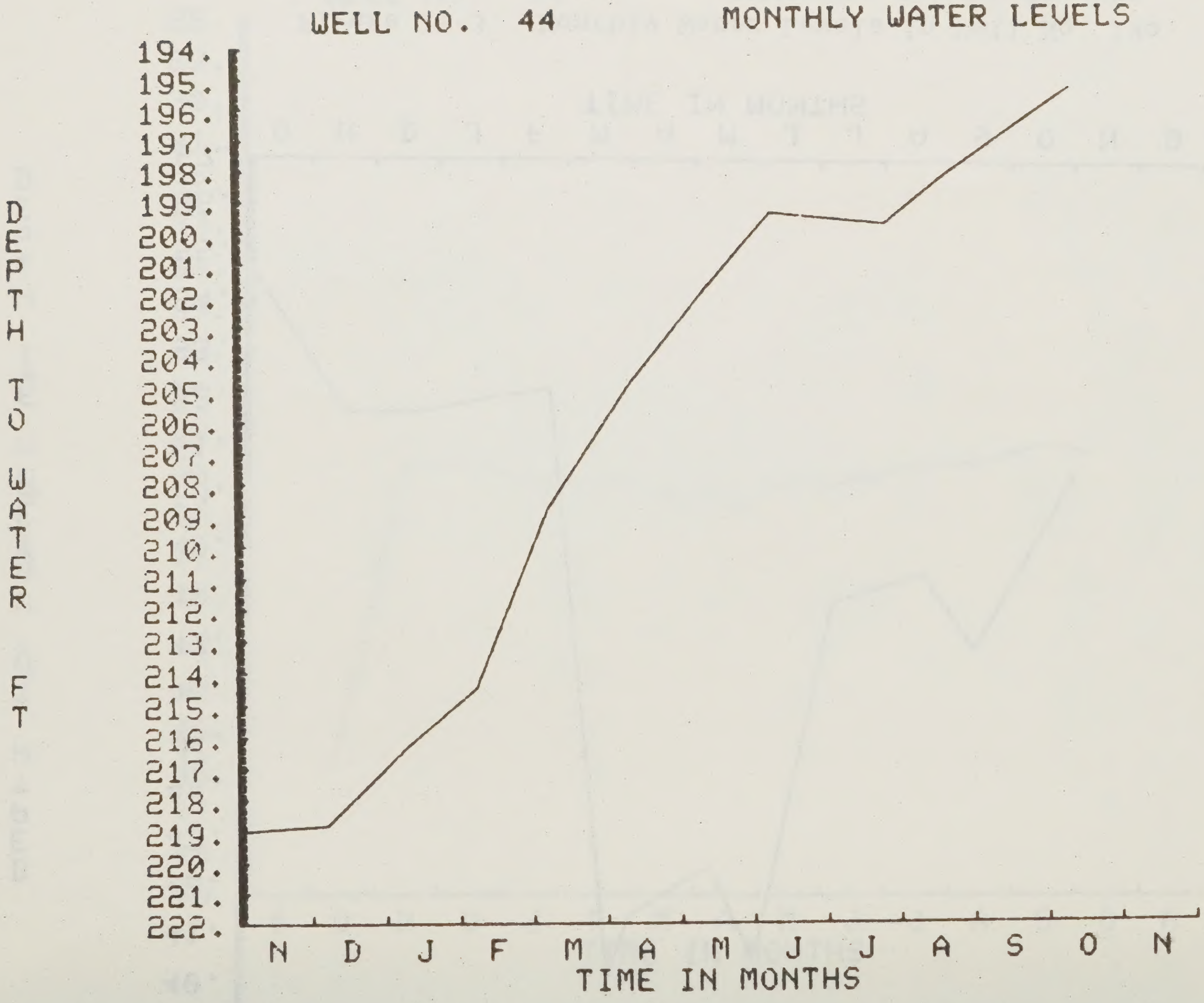
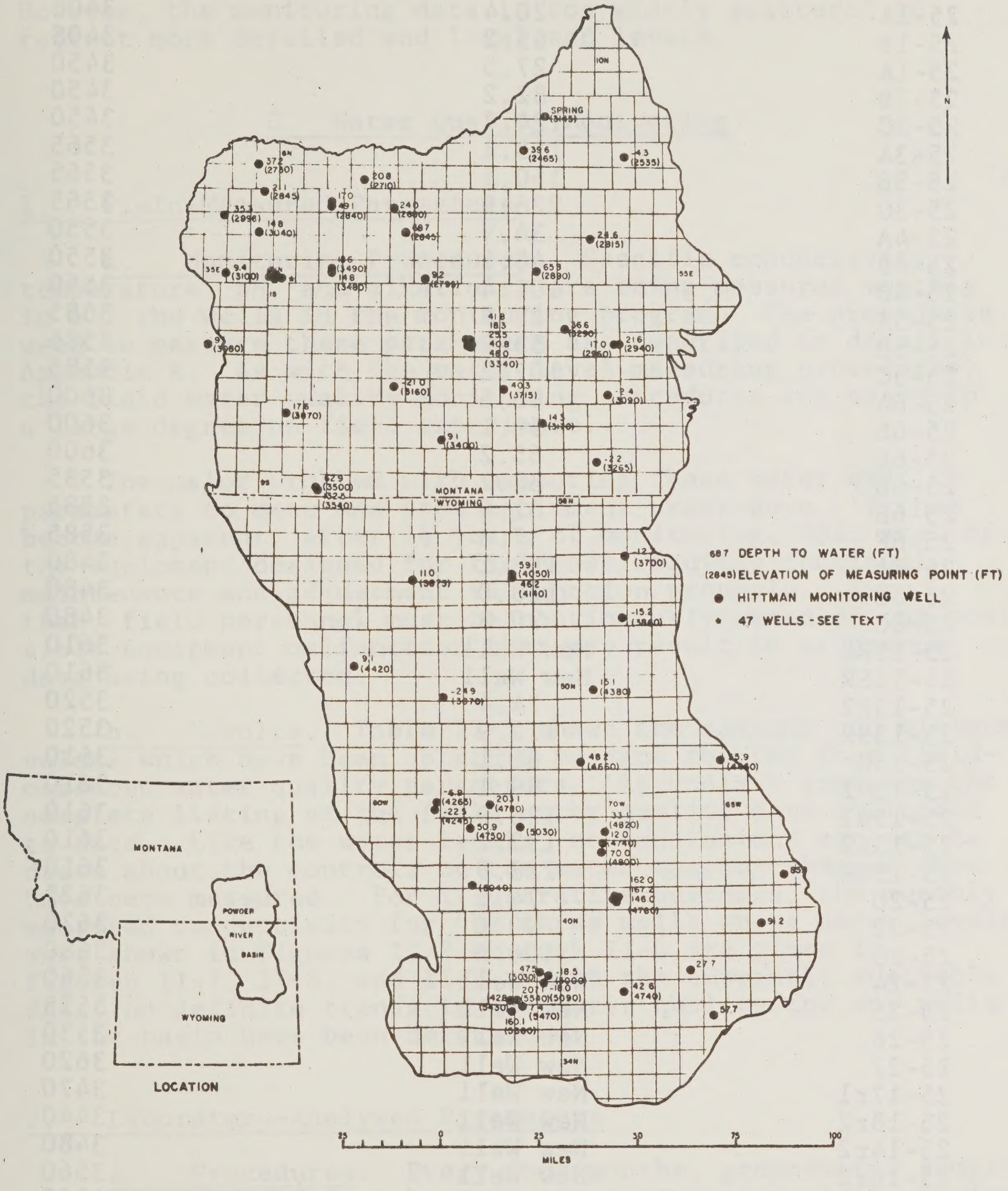


Figure II-4. Monthly Water Levels in Well No. 44



687 DEPTH TO WATER (FT)
(2845) ELEVATION OF MEASURING POINT (FT)
● HITTMAN MONITORING WELL
* 47 WELLS - SEE TEXT
N
SPRING (3165)
MONTANA
WYOMING
LOCATION
MONTANA
POWDER RIVER BASIN
WYOMING
10N
55E
9S
58N
50N
60W
65W
70W
40N
34N
25 0 25 50 75 100
MILES
37.2 (2780)
21.1 (2845)
35.3 (2996)
14.8 (3040)
9.4 (3100)
17.0
49.1 (2840)
20.8 (2710)
24.0 (2680)
68.7 (2845)
18.6 (3490)
14.8 (3480)
9.2 (2795)
39.6 (2465)
4.3 (2535)
24.6 (2815)
65.9 (2890)
9.1 (3080)
41.8 18.3 25.5 40.8 48.0 (3340)
36.6 (3290)
17.0 (2960)
21.6 (2940)
-21.0 (3160)
40.3 (3715)
-2.4 (3090)
17.6 (3070)
14.3 (3130)
9.1 (3400)
-2.2 (3265)
62.9 (3500)
32.4 (3540)
11.0 (3875)
59.1 (4050)
46.2 (4180)
-12.1 (3700)
-15.2 (3860)
9.1 (4420)
-24.9 (3870)
15.1 (4380)
48.2 (4660)
15.9 (4660)
-6.9 (4265)
-22.5 (4245)
20.3.1 (4780)
50.9 (4750)
(5030)
33.1 (4820)
12.0 (4740)
70.0 (4800)
(5040)
162.0 167.2 146.0 (4780)
85.9
91.2
47.5 (5030)
-18.5 (5000)
20.1 -18.0 (5580) (5090)
42.8 (5430)
7.4 (5470)
160.1 (5360)
27.7
42.6 (4740)
57.7

Figure II-5. Average Depth to Water in Observation Wells

TABLE II-2. WESTMORELAND RESOURCES WELLS

Well No.	Depth to Water (ft)	Surface Elevation (ft
25-1A	20.4	3408
25-1B	85.2	3408
25-1A	27.5	3450
25-2B	82.2	3450
25-2C	124.7	3450
25-3A	115.1	3565
25-3B	150.1	3565
25-3C	226.9	3565
25-4A	34.9	3550
25-4B	48.5	3550
25-4C	107.4	3550
25-5A	28.8	3585
25-5B	55.2	3585
25-5C	107.2	3585
25-6A	96.5	3600
25-6B	59.1	3600
25-6C	65.2	3600
25-6D	38.2	3585
25-6E	81.0	3585
25-6F	37.8	3585
25-8A	193.1	3480
25-8B	128.0	3480
25-8C	70.8	3480
25-12R2	New Well	3610
25-12SR	New Well	3610
25-13R2	74.4	3520
25-13SR	112.9	3520
25-150	61.1	3610
25-15R1	89.1	3610
25-15RI	126.9	3610
25-15R2	132.2	3610
25-15SR	228.9	3610
25-20	74.1	3625
25-22	90.6	3620
25-23	106.5	3680
25-24	New Well	3560
25-25	New Well	3515
25-26	New Well	3530
25-27	New Well	3620
25-17r1	New Well	3470
25-18r2	New Well	3440
25-14r2	New Well	3480
25-16r2	New Well	3560
25-16sr	New Well	3560
25-18	New Well	3560
25-19	New Well	3530
25-21	New Well	3550

is shown in Figure II-6. On a general basis, the contour map reflects the groundwater elevations in the study area. However, the monitoring data is too widely scattered to reflect more detailed and localized levels.

C. Water Quality Monitoring

1. Field-Measured Parameters

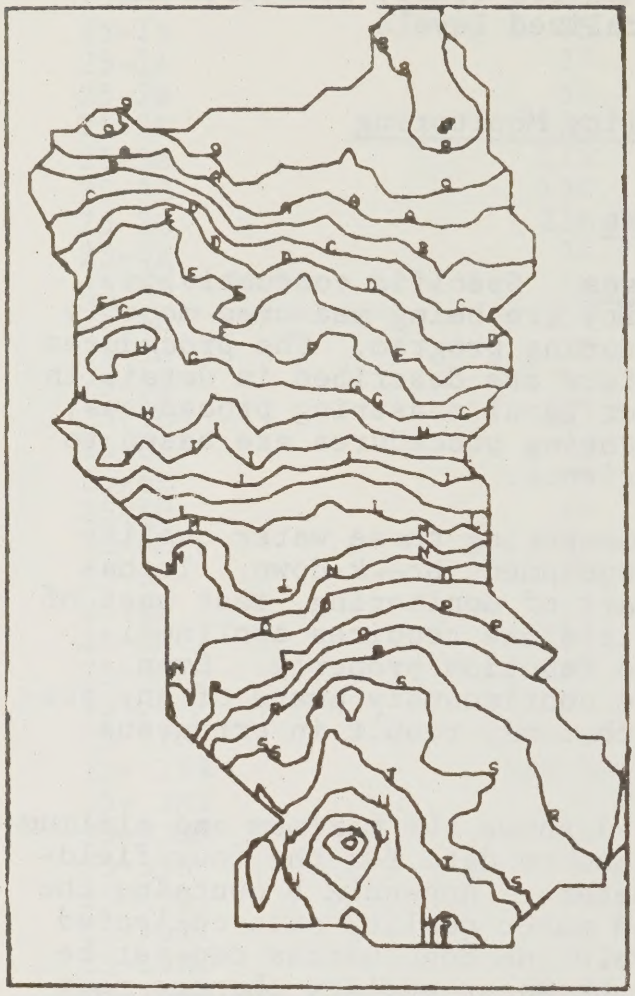
a. Monitoring Procedures. Specific conductivity, temperature, pH, and alkalinity are being measured monthly in all the wells in the monitoring program. The procedures used to measure these parameters are described in detail in Appendix A. As with the water level measuring procedures, the field water quality monitoring procedures are based to a large degree on field experience.

The major problem with measuring these water quality parameters to date has been equipment break-down. It has become apparent, after 1½ years of monitoring, that most of the equipment designed for field use requires continual maintenance and adjustment to function properly. Even then, field personnel must be continuously aware of any possible equipment malfunction that may result in erroneous data being collected.

b. Results. Table II-3 shows the maximum and minimum values which have been obtained to date for the four field-measured water quality parameters. Appendix B contains the complete listing of the field water quality data collected to date. Like the water levels, no conclusions can yet be drawn about the controls on the water quality changes that have been measured. For illustrative purposes, the monthly measured conductivity for the three wells whose water levels were shown in Figures II-2 through II-4 are given in Figures II-7, II-8, and II-9. With the currently available data, no definite trends in the water quality for any wells in the basin have been determined.

2. Laboratory-Analyzed Parameters

a. Procedures. Every four months, groundwater samples are collected and sent back to the Hittman Associates Environmental Chemical Laboratories in Columbia, Maryland. The samples are analyzed for sodium, calcium, magnesium, potassium, sulfate, chloride, nitrate, boron, total organic carbon, total dissolved solids, hardness, and one other parameter (presently



KEY

Symbol	Elev. (ft)
1	2000.
2	2100.
3	2200.
4	2300.
5	2400.
6	2500.
7	2600.
8	2700.
9	2800.
A	2900.
B	3000.
C	3100.
D	3200.
E	3300.
F	3400.
G	3500.
H	3600.
I	3700.
J	3800.
K	3900.
L	4000.
M	4100.
N	4200.
O	4300.
P	4400.
Q	4500.
R	4600.
S	4700.
T	4800.
U	4900.
V	5000.
W	5100.
X	5200.
Y	5300.
Z	5400.
@	5500.

Figure II-6. Computer-Generated Contour Map of Average Groundwater Elevation in Powder River Basin Based on Data from Monthly Monitoring Program

TABLE II-3. RANGES OF FIELD-MEASURED WATER QUALITY PARAMETERS

Parameter	Unit	Maximum Measured Value	Minimum Measured Value
Specific Conductivity	µmhos/cm	13,271	310
Temperature	^{o}C	20.0	0.0
pH	-	12.3	4.1
Alkalinity	mg/1 $CaCO_3$	2750	0

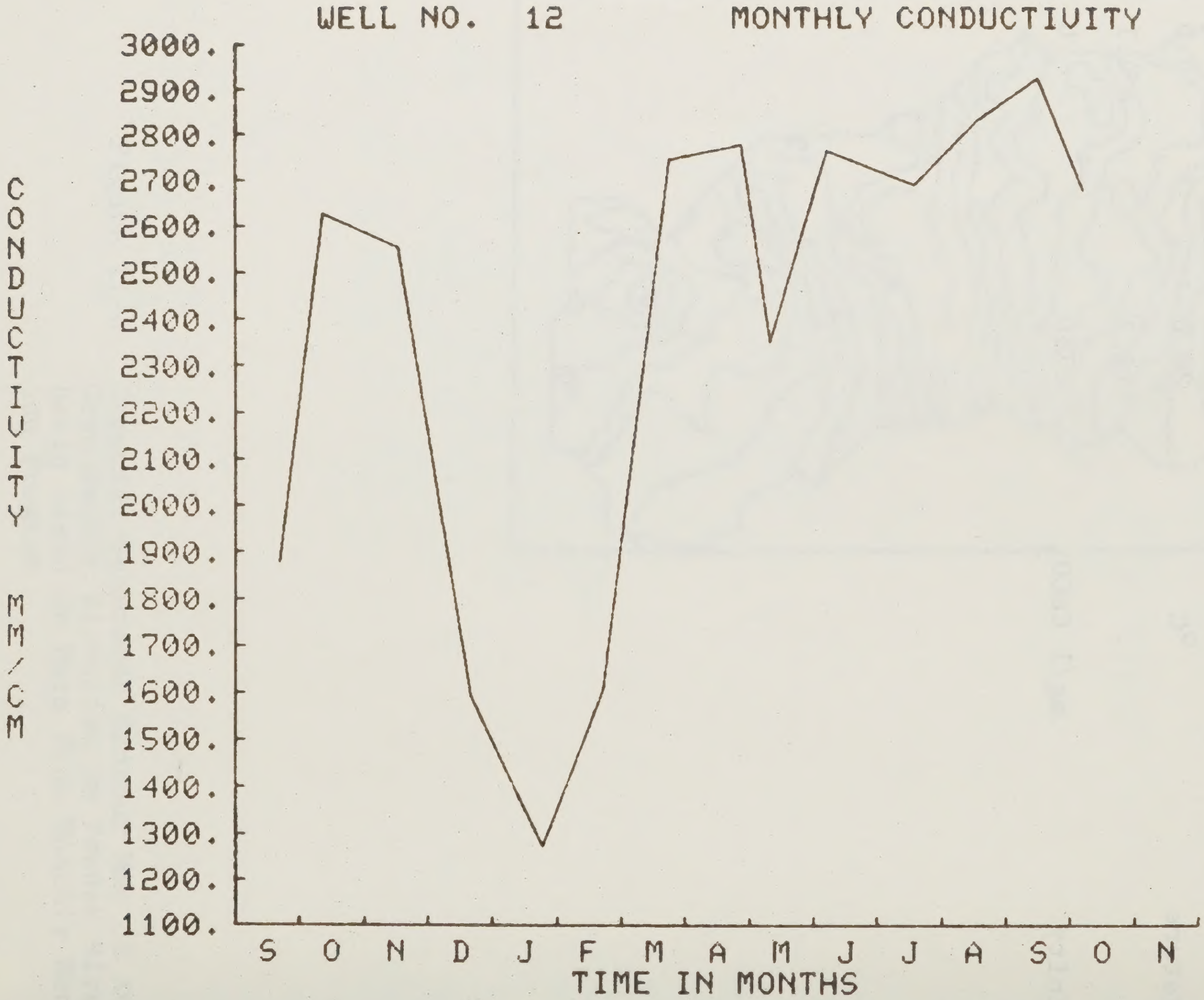


Figure II-7. Monthly Conductivity in Well No. 12

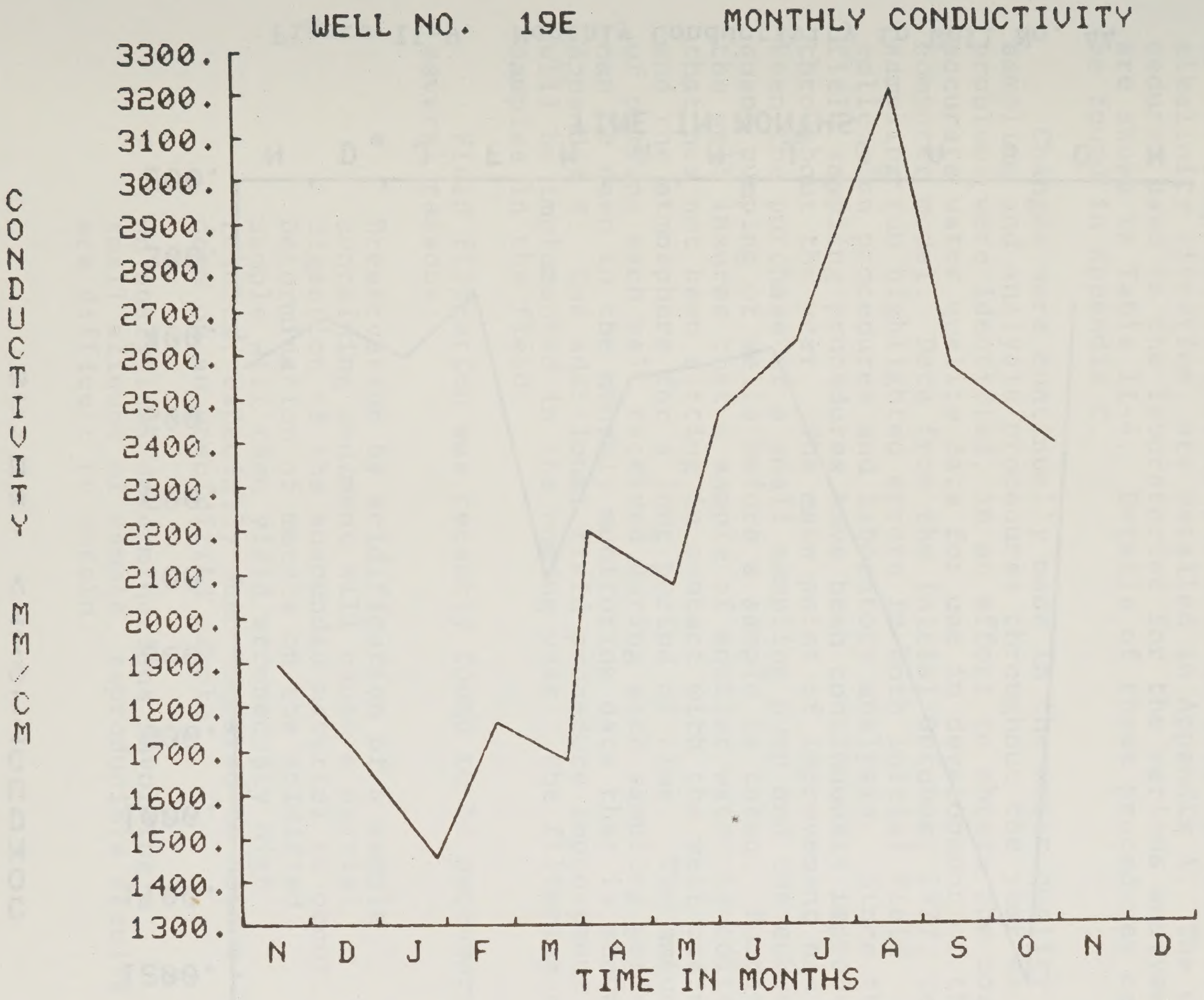


Figure II-8. Monthly Conductivity in Well No. 19e

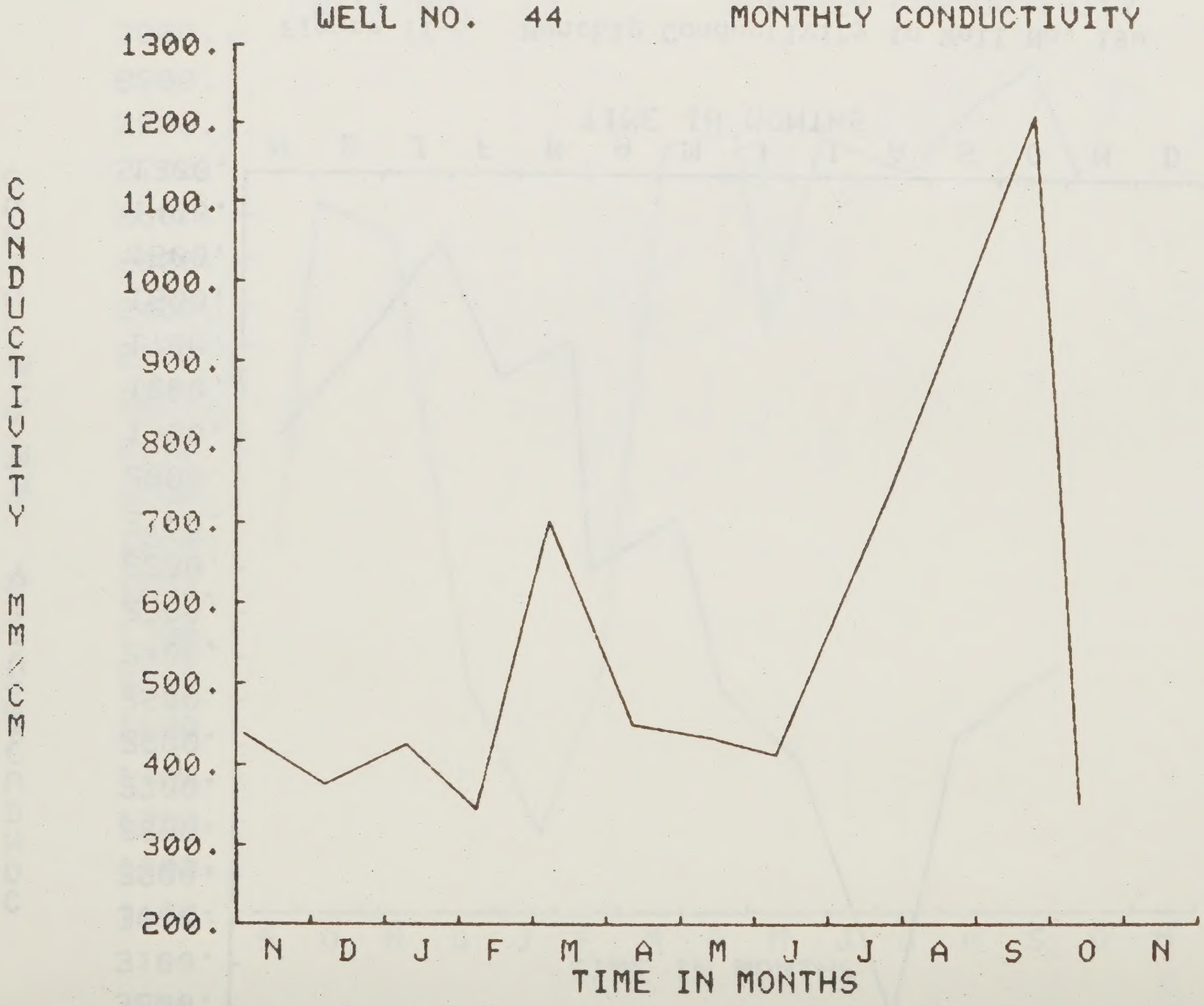


Figure II-9. Monthly Conductivity in Well No. 44

iron). Samples are also sent (beginning with the September, 1978, sample set) to Energy and Environmental Resource Consultants, Inc., a laboratory in Billings, Montana, to be analyzed for uranium and thorium. Bicarbonate is presently being determined every four months from an alkalinity titration which is performed in the field.

The procedures used for collection and preservation of the samples, as well as the methods used for the field alkalinity titration, are detailed in Appendix A. The procedures used in the laboratories for the various analyses are shown in Table II-4. Details of these procedures can be found in Appendix C.

Changes were continually made in the water quality sampling and analysis procedures throughout the year as problems were identified, in an effort to obtain the most accurate water quality data for use in development of the computer model. Data from the initial October, 1977, trial sampling run highlighted errors in both initial field collection procedures and laboratory analysis. Since then, field sampling procedures have been continuously improved throughout the year. The main point of improvement has been the purchase of a small sampling pump and the subsequent pumping of wells before a sample is taken. Pumping the well insures that a sample of aquifer water is collected that has not been sitting in contact with the well casing and the atmosphere for a long period of time. The amount of pumping each well received during each sampling period can be seen in the monthly monitoring data that is shown in Appendix B. One additional field procedure improvement will be implemented in the coming year: the filtering of samples in the field.

Field filtration was recently found to be necessary for several reasons:

- Preservation by acidification of a sample containing sediment will cause a partial digestion of the suspended material to occur. Determination of metals on the acidified sample will then yield erroneously high results, especially when compared to anions done on an unacidified sample.

- On analytical determinations involving a small aliquot of sample, reproducible results are difficult to obtain.

TABLE II-4. LABORATORY ANALYTICAL PROCEDURES

Parameter	Procedure
sodium	atomic adsorption
calcium	atomic adsorption
magnesium	atomic adsorption
sulfate	turbidimetric
potassium	atomic adsorption
boron	curcumin
total organic carbon	Oceanography International Carbon Analyzer
total dissolved solids	gravimetric
nitrate	specific ion electrode
chloride	specific ion electrode
hardness	EDTA titration
iron	atomic adsorption
uranium	extraction followed by fluorimetry
thorium	colorimetric

- It is an accepted principle of hydrogeology that little or no filterable sediment is present in groundwater. The sources of sediment in the water samples collected in the Powder River Basin to date are the formations in which the wells are completed. Sediment from this source is probably due to inadequate well packing, screening, and/or development. The object of the groundwater sampling program is to measure groundwater quality, not that of the sand in a well.

Field filtration was found to be necessary in spite of the fact that each well is pumped for 15 to 20 minutes before a sample is taken. Field experience has shown that some wells continue to discharge sediment-laden water even after being pumped for this period of time.

b. Results. The triannual water quality data is shown in Appendix D. No conclusions can be drawn from the data collected to date. There do not seem to be any regional trends in water quality in the Powder River Basin.

The predominant cations in the groundwater sampled are sodium, calcium, and magnesium. The predominant anions are sulfate and bicarbonate. There is a wide range of total dissolved solids concentration, from 212 mg/l to 7873 mg/l. Boron concentrations are generally less than 1.0 mg/l. Iron concentrations are generally low, but some are significant, ranging as high as 59 mg/l. Uranium and thorium concentrations are generally close to the limits of detection, one microgram/liter for uranium and 10 micrograms/liter for thorium. Nitrate concentrations are generally low, with a few wells having nitrate concentrations in excess of 3 mg/l.

The water quality analysis program has yielded one interesting result. The total organic carbon (TOC) concentrations are higher than one would expect. The average TOC concentration found in the September, 1978, sampling was 4.05 mg/l; the highest concentration found was 28.8 mg/l. If these measured TOC's were completely biodegradable, the respective ultimate biodegradable oxygen demands would be approximately 10.8 mg/l and 77 mg/l. These are much higher concentrations of organics than one would expect to find in groundwater. One possible reason for these concentrations of organics is the fact that the aquifers throughout the Powder River Structural Basin are often coal beds. Coal is an organic compound. As water flows through the coal beds, organics may be leached from the coal. One possibility for future research would be to identify the compounds that compose TOC in these groundwaters, and ascertain their effects on human health. Health effects are of interest because many of the wells sampled are used for domestic purposes, and the organics found in coal are not simple sugars, but rather phenolic and polynuclear aromatic compounds which are suspected carcinogens.

D. Quality Assurance

In any data collection program, some method of assuring the reliability of the data is necessary. An explicit quality assurance program provides for validation of all phases of the data collection procedure, as well as tests of accuracy and precision.

There are a number of techniques that may be used in a quality assurance program. Some of the techniques that are used in this program are: technician and operator training, a continued program of quality control testing, manual verification of transcribed data, and computer-implemented checking of data. Specific quality assurance procedures have been implemented for both field and laboratory operations.

1. Field Quality Assurance

The primary mission of the field crews based in the Billings, Montana office is the collection of groundwater level and quality data on a monthly basis. The quality assurance program for this activity has two main components.

The most important part of the field quality assurance program is the detailed, written procedure for all monitoring and maintenance. The text of this procedure is in Appendix A. The procedure that appears in Appendix A is the latest version. It has been frequently revised as new field conditions have arisen, and new equipment has been obtained. The written procedure details specific methods for measuring of well water levels; collection of water samples; analyses for temperature, conductivity, pH, and alkalinity; and maintenance of the equipment.

The second component of the field quality assurance program is quality control tests of the field crew's analyses of water quality. These quality control tests are administered by preparing specific solutions with known pH, alkalinity and/or conductivity. These unknowns are then given to each member of the field crew for analysis. The field crew members have no knowledge of the correct answers, thus providing a blind test.

Two quality control tests have been administered in the past year. The results are shown in Table II-5. The mean value column in Table II-5 contains the average values reported by three technicians.

The data in Table II-5 are too limited to draw conclusions about accuracy and precision, although it is clear that there are some problems with the conductivity measurements. The errors in conductivity stem from the equipment itself, a YSI Model #33 SCT Meter. This piece of equipment has an accuracy of ± 3 percent at best (YSI Model #33 SCT Meter Instruction Manual) and this error does not include error due to the probe. When error due to the probe and operator are included, it seems that total equipment error itself is in excess of 10 percent.

2. Laboratory Quality Assurance

At four month intervals, groundwater samples are collected and sent via air freight to the Hittman Associates' Environmental Chemical Laboratories in Columbia, Maryland. At the Hittman laboratory, samples are analyzed for sodium, calcium, magnesium, potassium, sulfate, chloride, nitrate, boron, total dissolved solids, hardness, total organic carbon, and one other parameter (presently iron).

The mainstay of the laboratory quality assurance program is the written quality assurance plan which is shown in Appendix E. The quality assurance plan provides specific directions for sampling, sample preservation, sample custody, and analysis quality control. This quality control program provides for certification of each analyst for each parameter followed by daily control sample checks.

In addition to this rigorous internal laboratory quality control program, a quality control program is also administered by project staff that is not connected with the laboratory. Duplicate and reference samples are sent in with the triannual sample submissions. These duplicates and/or reference samples are marked similarly to the other bottles, thus giving the laboratory a blind test.

TABLE II-5. QUALITY CONTROL TEST RESULTS

	Test #1 7/25/78			Test #2 11/2/78		
Parameter	Theoretical Value	Mean Value (N=3)	Standard Deviation (N=3)	Theoretical Value	Mean Value (N=3)	Standard Deviation (N=3)
Conductivity (micromhos/cm)	718	626	15	2767	2130	572
Total Alkalinity (mg/l as $CaCO_3$) (microburette)	1000	968	65	3125	3049	146
pH	11.0	10.8	0.1	10.0	10.0	0

Two of these quality control tests have been implemented in the past year. The results for two sets of duplicate samples that were submitted with the May, 1978, sample collection are shown in Table II-6. The major errors in this quality control test were found to be all due to clerical errors; the data for May, 1978, was reviewed and the clerical errors corrected.

A more extensive quality control test was administered with the September, 1978, samples. Four sets of duplicates were submitted to the Hittman laboratory, and these same four sets of duplicates were also submitted to an independent laboratory, Energy and Environmental Resource Consultants (EERC) in Billings, Montana. The results reported for these duplicates are shown in Table II-7. Unfortunately, the results are not directly comparable between the laboratories because of different sample preparation procedures used by each laboratory. The Hittman (HAI) laboratory filtered all the samples before analysis; EERC did not. In addition, the total dissolved solids (TDS) determination of the Hittman laboratory was done at 104°C; EERC ran TDS at 180°C.

The results shown in Table II-7 are good. The HAI laboratory's results are obviously much improved over the May quality control test.

One additional quality control test was administered in September, 1978. A reference sample was submitted to the Hittman laboratory. The results of the analyses on this reference sample are shown in Table II-8. Given the accuracy of the reference sample, about ± 10 percent, the results shown in Table II-8 are excellent.

Future water quality data will be checked internally for its consistency by three methods. The first of these is a cation-anion balance for each sample. The cation-anion balance relies on the fact that there must be charge neutrality between the cations (+) and anions (-) in a water sample. If all of the major ions in solution are determined, the sum of the cation equivalents should equal the anion equivalents. Small imbalances would be due to unmeasured trace constituents and normal analytical error. Large imbalances would be due to an improper determination of one of the major cations (Na, Ca, Mg, or K) or anions (SO_4, HCO_3, Cl).

The second internal check that will be applied to the water quality data is a comparison of calculated hardness to measured hardness. Hardness may be defined as the sum

TABLE II-6. RESULTS OF DUPLICATE ANALYSES - May, 1978

Parameter	#Hd	#69	Difference (%)
Na (mg/l)	58.7	486.	88
Ca (mg/l)	5.3	5.6	5
Mg (mg/l)	2.8	27.7	90
SO_4 (mg/l)	609.0	609.0	0
B (mg/l)	nothing reported	.10	-
TDS (mg/l)	894	1762	49
TOC (mg/l)	8.1	8.1	0
NO_3 (mg/l)	0.0	0.0	0
Hardness (mg/l)	196.0	196.0	0
K (mg/l)	9.5	9.5	0
Cl (mg/l)	nothing reported	nothing reported	-
Fe (mg/l)	3.7	1.1	70

DUPLICATE SET NO. 2

Parameter	#47	#68	Difference (%)
Na	780.0	73.0	91
Ca	7.6	8.1	6
Mg	5.0	5.1	2
SO_4	537.0	550.0	2
B	0.06	0.04	33
TDS	1866	1602	14
TOC	2.70	4.0	32
NO_3	0.1	0.0	100
Hardness	131.0	1165.0	89
K	4.6	5.1	10
Cl	11.5	8.1	30
Fe	0.3	0.6	50

TABLE II-7. RESULTS OF DUPLICATE ANALYSES - September, 1978

DUPLICATE SET NO. 1

Parameter	HAI			EERC		
	#69	#71	Diff.(%)	#69	#71	Diff.(%)
Na (mg/l)	240.0	238.0	1	253	257	2
Ca (mg/l)	34.0	34.0	0	35	35	0
Mg (mg/l)	9.3	9.0	3	5	9	44
SO_4 (mg/l)	409.0	409.0	0	419	431	3
B (mg/l)	0.11	0.12	8	< 0.05	< 0.05	0
TDS (mg/l)	933	766	18	842	848	1
TOC (mg/l)	1.60	1.70	6	-	-	-
NO_3^-N (mg/l)	1.0	1.0	0	.19	.27	30
Hardness (mg/l)	112.0	134.0	16	106	129	18
K (mg/l)	2.7	3.0	10	4.0	4.0	0
Cl (mg/l)	10.0	10.0	0	11	11	0
Fe (mg/l)	0.3	0.3	0	-	-	-

DUPLICATE SET NO. 2

Parameter	HAI			EERC		
	#15	#31	Diff.(%)	#15	#31	Diff.(%)
Na	187.0	187.5	0	180	182	1
Ca	0.7	0.7	0	2	2	0
Mg	0.4	0.4	0	1	1	0
SO_4	107.0	105.0	2	140	138	1
B	0.20	0.20	0	0.11	0.09	18
TDS	393	431	9	485	492	1
TOC	1.00	1.10	9	-	-	-
NO_3^-N	0.1	0.8	88	0	0.07	100
Hardness	17.0	25.0	32	7	7	0
K	1.0	1.0	0	1	1	0
Cl	15.0	14.0	7	10	10	0
Fe	< 0.1	< 0.1	0	-	-	-

TABLE II-7 (Continued)

DUPLICATE SET NO. 3

	HAI			EERC		
Parameter	#56	#68	Diff.(%)	#56	#68	Diff.(%
Na	318.0	315.0	1	310	310	0
Ca	3.2	3.2	0	4	4	0
Mg	1.6	1.3	19	1	1	0
SO_4	138.0	138.0	0	179	181	1
B	0.24	0.23	4	.12	.13	8
TDS	760	693	9	783	772	1
TOC	1.60	3.40	53	-	-	-
NO_3^-N	0.2	0.5	60	0	.05	100
Hardness	34.0	34.0	0	14	14	0
K	1.8	1.7	6	2	2	0
Cl	23.0	21.0	9	12	14	14
Fe	< 0.1	< 0.1	0	-	-	-

DUPLICATE SET NO. 4

	HAI			EERC		
Parameter	#28A	#32	Diff.(%)	#28A	#32	Diff.(%
Na	502.0	519.0	3	510	520	2
Ca	24.1	24.0	0	29	29	0
Mg	7.7	8.1	5	6	6	0
SO_4	780.0	797.0	2	852	852	0
B	0.20	0.20	0	0.09	0.12	25
TDS	1351	1437	6	1608	1619	0
TOC	2.10	2.40	12	-	-	-
NO_3^-N	0.7	0.2	71	0	0	0
Hardness	99.0	126.0	21	96	96	0
K	4.0	4.0	0	5	6	17
Cl	11.5	11.5	0	10	8	20
Fe	2.0	2.0	0	-	-	-

TABLE II-8. REFERENCE SAMPLE ANALYSIS

Parameter	Known Value	HAI Lab	Error(%)
Na (mg/l)	67.8	56.5	17
Ca (mg/l)	0	0	0
Mg (mg/l)	0	0	0
SO_4 (mg/l)	80.0	88.0	10
B (mg/l)	0	0	0
TDS (mg/l)	227	264	16
TOC (mg/l)	0	1.3	-
NO_3^--N (mg/l)	0	0.1	-
Hardness (mg/l)	0	0	0
K (mg/l)	41.2	34.0	17
Cl (mg/l)	37.4	37.0	1
Fe (mg/l)	0	0	0

HITMAN

of the divalent cation equivalents. The major divalent cations are calcium and magnesium. Thus, hardness can be calculated by totaling the measured equivalent concentrations of calcium and magnesium and converting this number to milligrams of $CaCO_3$, the traditional method of expressing hardness. Small errors in this comparison would be due to normal analytical error and the presence of other divalent cations. Large errors would indicate an error in the analyses of calcium, magnesium, or hardness.

A third internal check that will be applied to the water quality data is a comparison of measured total dissolved solids (TDS) to calculated total dissolved solids. Calculating TDS by summing the individual constituents is an improper procedure for this comparison. The residue determination done in the laboratory (at 104°C)cause changes in the constituents. Allowances must be made for the loss of bicarbonate ion as carbon dioxide, and the hydration of many sulfate compounds. These allowances can be approximated using the procedure of Sokoloff (Ref. 3). This procedure predicts a specific order in which compounds will precipitate during the evaporation procedure. Each compound has a molecular weight assigned to it that includes such factors as water of hydration and loss of bicarbonate. The accuracy and validity of this procedure is still open to question, however, it should provide a method of detecting gross errors in the chemical analyses.

The internal checking procedures for the water quality data described above are contained in a computer program that is used to prepare the water quality data for the data management system. The FORTRAN code of this computer program is shown in Appendix F.

None of the internal checking procedures described above have been applied to the water quality monitoring data collected so far. The reason for this is the large amount of sediment found in many samples. Sediment prevents an accurate cation-anion balance. Cation analyses are run on an acidified sample; the anions are run on an unacidified sample. Acidification of a sample digests some of the sediment, thus adding to the cation concentrations. As mentioned previously, future water quality samples will be filtered in the field before acidification.

III. ACQUISITION OF PUBLISHED AND UNPUBLISHED DATA

The literature review continues. Newly released reports on the geology, hydrogeology, and overall environment of the Powder River Basin are constantly being reviewed.

One tangible and valuable output of the literature review task is a computer databank of published observation well and groundwater data. Within this databank there are two files. The first file contains information on well location, elevation, depth, diameter, screened or perforated interval, aquifer name and/or description, specific capacity, water level, pH, temperature, conductivity, total alkalinity, and date of observations for all acquired well data. The second file contains detailed water quality information. The first file contains 1329 observations from approximately 970 wells. The water quality file contains 499 observations from approximately 400 wells. The data in these files was compiled from the sources listed in Table III-1.

TABLE III-1. SOURCES FOR PUBLISHED AND UNPUBLISHED DATA IN THE COMPUTER DATABANK

Davis, R.W. and Rechard, P.A., Effects of Surface Mining on Shallow Aquifers in the Eastern Powder River Basin, Wyoming, Water Resources Research Institute, University of Wyoming, Laramie, May 1977.

Hodson, 1975, unpublished data.

Lowrey, M.E. and Cummings, T.R., 1966, Groundwater Resources of Sheridan County, Wyoming, USGS Water Supply Paper 1807.

Miller et al, 1977, Well Appropriation Data for Southeastern Montana - Big Horn, Carter, Custer, Fallon, Powder River, Rosebud, and Treasure Counties, Open File HY77-2, Montana College of Mineral Science and Technology, Butte, Montana.

Peabody Coal Company, 1974, Environmental Assessment Report for a Proposed Surface Coal Mine at North Antelope Creek.

Peabody Coal Company, 1977, Hydrologic Survey, Big Sky Mine.

Taylor, O.J., 1968, Ground Water Resources of the Northern Powder River Valley, Southeastern Montana, Bulletin 66, Montana College of Mineral Science and Technology, Butte, Montana.

U.S. Department of the Interior, Bureau of Land Management, 1977, Resource and Potential Reclamation Evaluation, Bear Creek Study Area - West Moorhead Coalfield, EMRIA Report #8.

U.S. Department of the Interior, Geological Survey, 1977, Proposed 20 Year Plan of Mining and Reclamation, Westmoreland Resources Tract III, Crow Indian Ceded Area, Montana, Final Environmental Statement.

U.S. Geological Survey, 1974, Shallow Ground Water in Selected Areas in the Fort Union Coal Region, Open File Report 74-371, Helena, Montana.

Van Voast, W.A.; Hedges, R.B.; McDermott, J.J.; Hydrogeological Conditions and Projections Related to Mining Near Colstrip, Southeastern Montana, Bulletin 102, Montana College of Mineral Science and Technology, Butte, Montana.

TABLE III-1. (Continued)

Van Voast, W.A.; Hedges, R.B.; McDermott, J.J.; Hydrologic Characteristics of Coal-Mine Spoils, Southeastern Montana, MUJWRRC Report No. 94, Montana University Joint Water Resources Research Center, Bozeman, Montana, June 1978.

IV. DETERMINATION OF AQUIFER CHARACTERISTICS

A. Background

The value of the hydrologic characteristics of the aquifers throughout the Powder River Structural Basin need to be accurately determined for development of the computer model. Determination of these characteristics, through well pumping and recovery tests, continued throughout the past year.

Long term pumping tests were conducted by utilizing the specially designed and fabricated mobile aquifer test trailer. This test trailer, shown in Figure IV-1, minimizes the logistics problems usually associated with large scale pumping tests. The trailer contains all major equipment necessary for performing pumping tests and thus eliminates the need to hire either a well driller or well servicing company to raise and lower the pump for each test.

The remainder of this section presents the results of the pumping and recovery tests performed over the past year.

B. Hanic Long Term Test

1. Site Characteristics

This pumping test site is located on the Hanic Ranch, in Sec. 14, T3S, R46E, approximately 12 miles east of Ashland, Montana. The layout of the pumped and observation wells is shown in Figure IV-2. The casing (PVC) in all of the wells was slotted over the entire depth of each well. Water levels had been measured in the wells on a monthly basis for nine months prior to the test.

As shown in Figure IV-2, the water levels in wells 19b and 19c are at a shallower depth than in 19a, 19d, or 19e even though the surface elevations of the measuring points of the two former wells are higher than the other three. After elevation differences between the various wells are taken into account, the static water levels in wells 19b

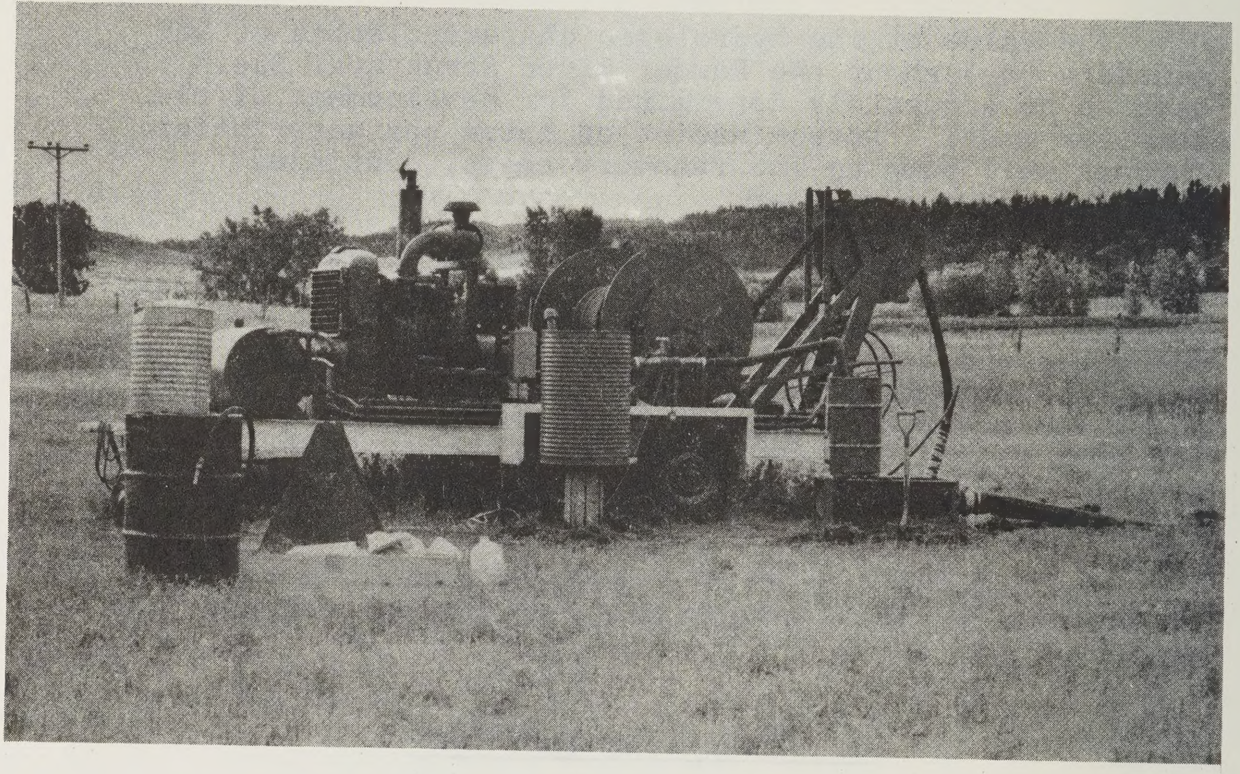


Figure IV-1. Mobile Aquifer Test Trailer

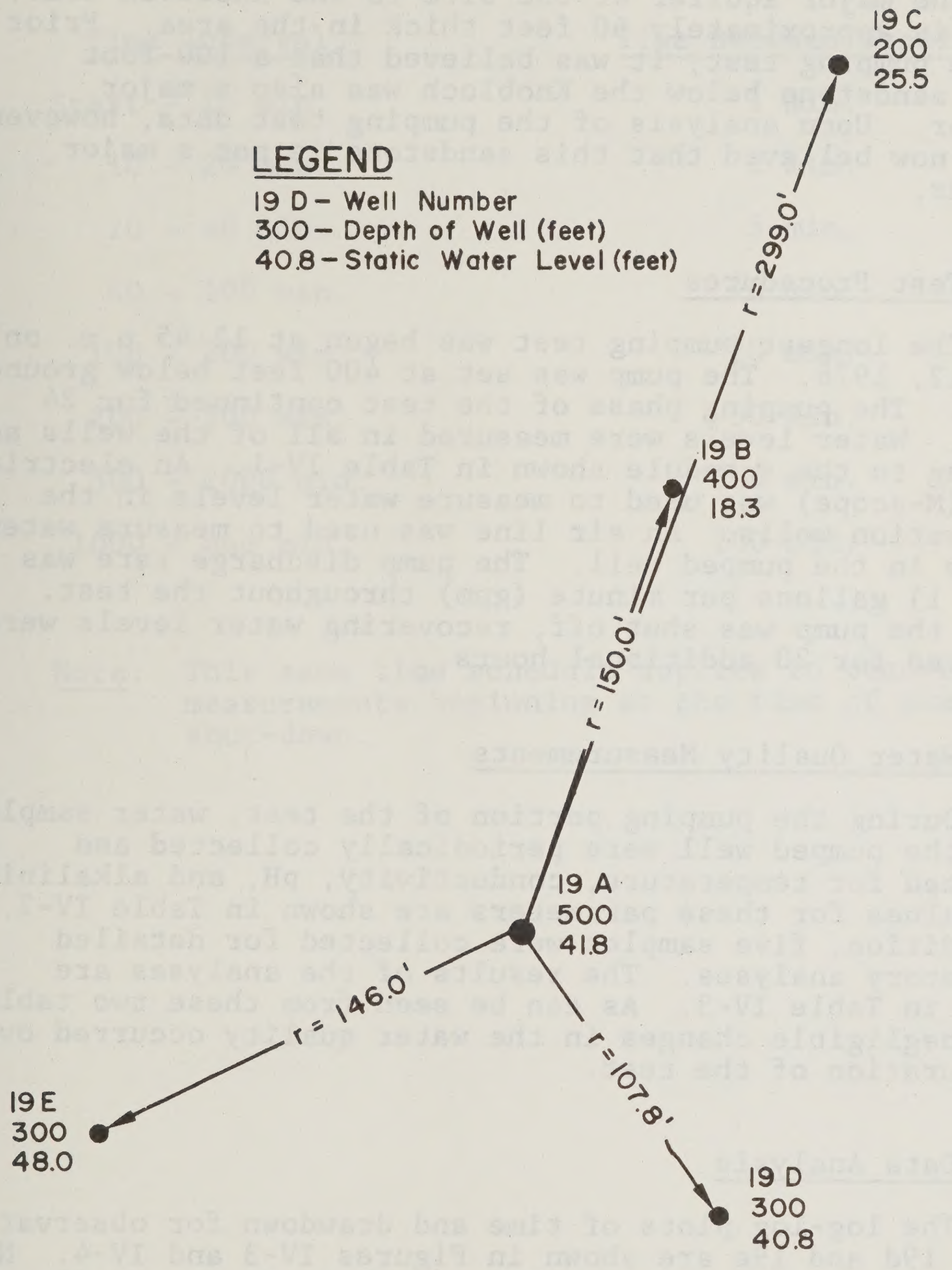

19 C
200
25.5
LEGEND
19 D – Well Number
300 – Depth of Well (feet)
40.8 – Static Water Level (feet)
r = 299.0'
19 B
400
18.3
r = 150.0'
19 A
500
41.8
r = 146.0'
r = 107.8'
19 E
300
48.0
19 D
300
40.8

Figure IV-2. Layout of Hanic Pumping Test Site

and 19c are approximately 30 feet higher than the other three wells. This is in spite of the fact that all of the wells penetrate the same major aquifer.

The major aquifer at the site is the Knobloch coal, which is approximately 60 feet thick in the area. Prior to the pumping test, it was believed that a 100-foot thick sandstone below the Knobloch was also a major aquifer. Upon analysis of the pumping test data, however, it is now believed that this sandstone is not a major aquifer.

2. Test Procedures

The longest pumping test was begun at 12:45 p.m. on July 12, 1978. The pump was set at 400 feet below ground level. The pumping phase of the test continued for 24 hours. Water levels were measured in all of the wells according to the schedule shown in Table IV-1. An electric tape (M-scope) was used to measure water levels in the observation wells. An air line was used to measure water levels in the pumped well. The pump discharge rate was 50 (± 1) gallons per minute (gpm) throughout the test. After the pump was shut off, recovering water levels were measured for 20 additional hours.

3. Water Quality Measurements

During the pumping portion of the test, water samples from the pumped well were periodically collected and analyzed for temperature, conductivity, pH, and alkalinity. The values for these parameters are shown in Table IV-2. In addition, five samples were collected for detailed laboratory analyses. The results of the analyses are shown in Table IV-3. As can be seen from these two tables, only negligible changes in the water quality occurred over the duration of the test.

4. Data Analysis

The log-log plots of time and drawdown for observation wells 19d and 19e are shown in Figures IV-3 and IV-4. No drawdown occurred in wells 19b and 19c. The small fluctuations in the water levels in these two wells can be attributed solely to measurement errors. Since no drawdown

TABLE IV-1. PUMPING TEST WATER LEVEL MEASURING SCHEDULE

Time Interval	Time Between Readings
Start - 10 min.	1 min.
10 - 20 min.	2 min.
20 - 40 min.	5 min.
40 - 100 min.	10 min.
100 - 200 min.	20 min.
200 - 300 min.	50 min.
300 - 1000 min.	100 min.
1000 - end min.	200 min.

Note: This same time schedule applies to recovery measurements beginning at the time of pump shut-down.

TABLE IV-2. WATER QUALITY PARAMETERS MEASURED DURING LONG TERM PUMPING TEST

Time Collected	Temperature (°C)	Conductivity ($\frac{\mu mhos}{cm}$ @ 25°C)	Alkalinity (mg/l $CaCO_3$)	pH
7/12 - 1245	Start of test			
1300	13	2767	734	7.4
1320	13	2767	760	7.3
1347	12.8	2806	736	7.4
1405	14.0	2900	714	7.2
1451	13.0	2781	726	7.2
1546	12.7	2796	734	7.2
1847	12.4	2787	716	7.1
2140	12.8	2751	706	7.2
7/13 - 0215	12.4	2773	728	7.4
0855	13.0	2726	702	7.3
1040	12.5	2781	718	7.4
1227	13.1	2762	726	7.3
Average	12.9	2783	725	
Stand. Dev.	0.43	42.4	15.6	

TABLE IV-3. DETAILED WATER QUALITY ANALYSES FROM SAMPLES TAKEN DURING PUMPING TEST

	Time Sample Collected (test started at 12:45 p.m., 7/12/78)				
	7/12		7/13		
Parameter	1405	1546	0215	0855	1227
	Parameter Value (in mg/l)				
Na	758.0	730.3	744.0	761	789.0
Ca	60.7	68.0	57.9	58.5	61.3
Mg	83.1	68.7	68.7	73.5	69.9
SO_4	822.0	858.0	822.0	822.0	822.0
HCO_3	871.1	895.5	888.2	856.4	885.7
B	0.21	0.16	0.18	0.21	0.19
TDS	1873	1831	1836	1876	1819
TOC	5.1	5.8	5.5	5.5	5.2
Nitrate	1.8	2.0	1.8	1.8	1.8
Hardness	451.0	432.0	440.0	407.0	414.0
K	15.5	15.7	13.6	13.5	16.0
Cl	8.0	9.2	8.0	10.0	10.0
Fe	1.5	2.2	0.34	0.43	0.68

occurred in these wells, no transmissivity or storage coefficients could be calculated for this area of the aquifers.

Significant drawdowns occurred in wells 19d and 19e (Figures IV-3 and IV-4). For well 19d, a Theis type curve was fit through the data for time (t) > 20 minutes. The data collected before this time does not fit any portion of the type curve and was therefore not used in the aquifer characteristics analysis. For well 19d, the transmissivity (T) was calculated to be 546 gallons per day per foot (gpd/ft) and the storage coefficient (S) was calculated as 2.96×10^{-4}.

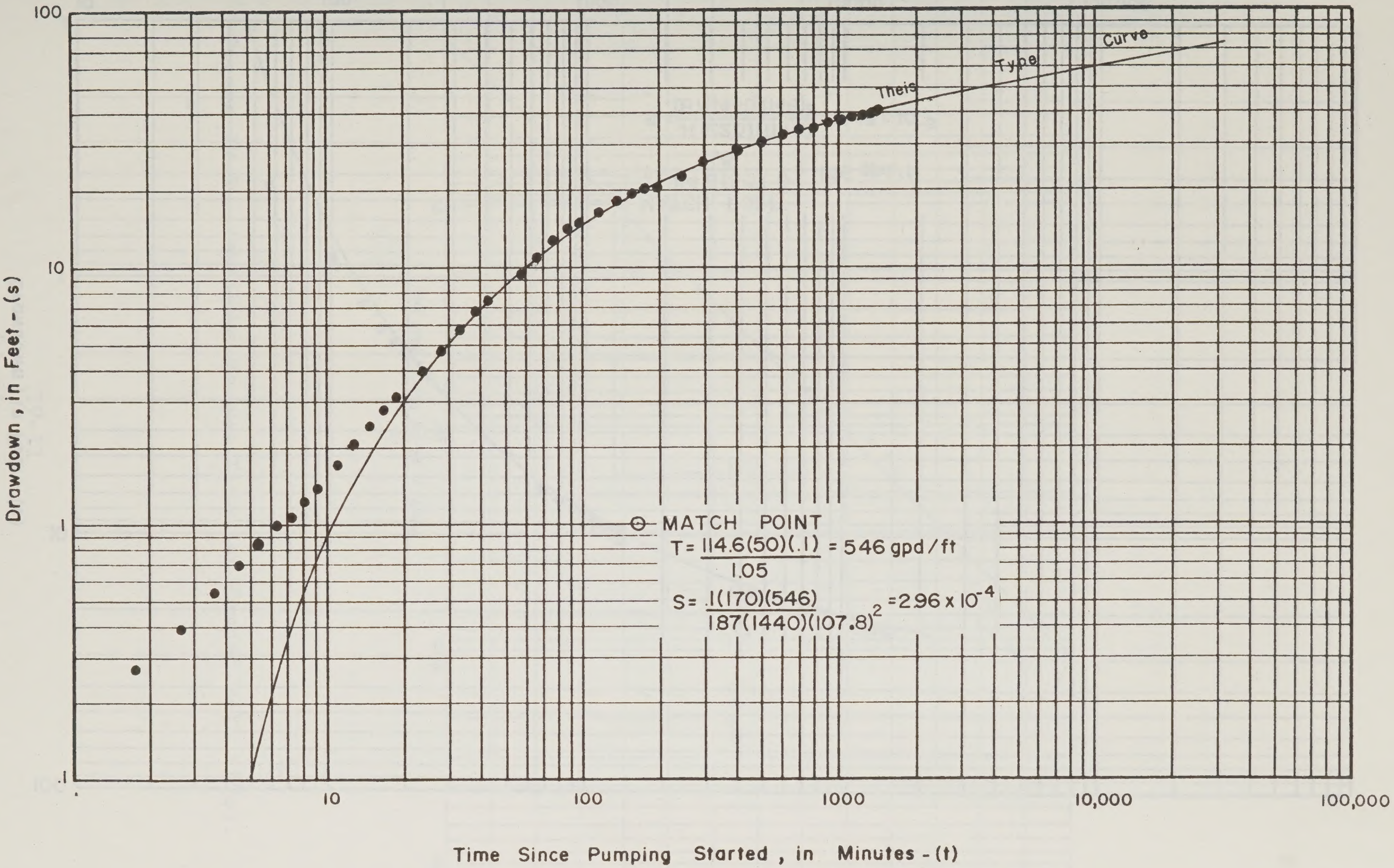
The drawdown in well 19e was similar to 19d in that the early drawdowns, those before t = 100, could not be fit to the type curve and were therefore excluded from the analysis of the data from this well. No drawdown occurred in 19e until about 10 minutes after pumping was started. The transmissivity for this well was calculated to be 1146 gpd/ft and the storage coefficient was calculated as 2.45×10^{-3}.

Time-drawdown data from a pumped well can only be used to estimate the aquifer transmissivity and cannot be used to determine the storage coefficient. A semilog plot of time and drawdown for the pumped well (19a) is shown in Figure IV-5. It is evident that the drawdown data before t = 10 minutes yields a curve with a flatter slope than the data after this time. The Cooper-Jacob method of analysis (Appendix G) can be used to analyze the data from the pumped well with no significant error. Using this method for the data after t = 10 minutes, the transmissivity was calculated as 106 gpd/ft.

5. Conclusions

The main reason that the early drawdown data from wells 19a, 19d, and 19e could not be used in the analysis of the aquifer characteristics is the fact that there was a significant volume of water in the casing of the pumped well (19a). This water had to be pumped out before the aquifers were significantly affected by the pumping.

One basic assumption of theoretical aquifer characteristics analysis methods is that the initial volume of water



⊙ MATCH POINT

$$T = \frac{114.6(50)(.1)}{1.05} = 546 \text{ gpd/ft}$$

$$S = \frac{.1(170)(546)}{1.87(1440)(107.8)^2} = 2.96 \times 10^{-4}$$

Figure IV-3. Drawdown Versus Time for Well 19d.

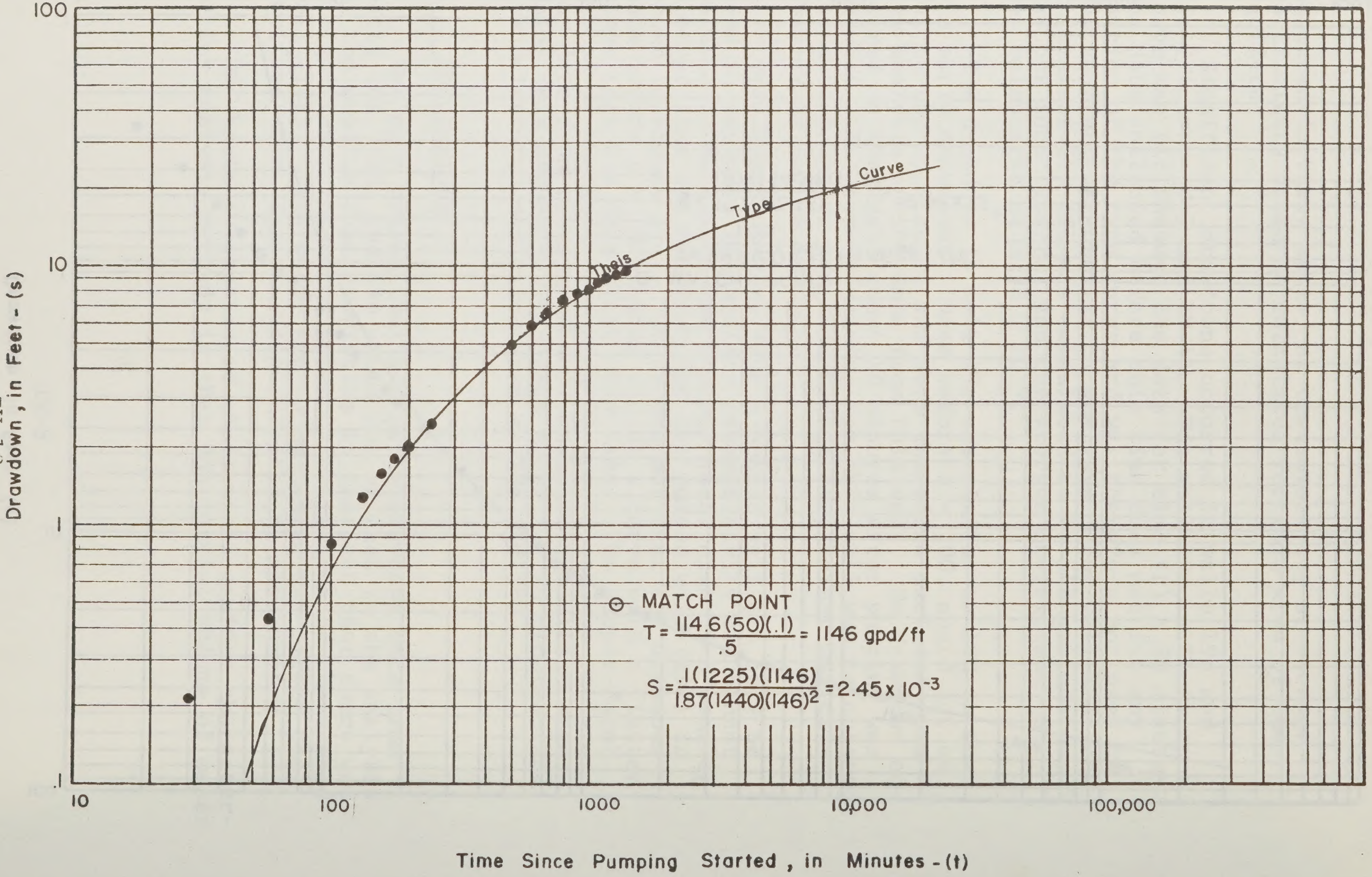


Figure IV-4. Drawdown Versus Time for Well 19e.

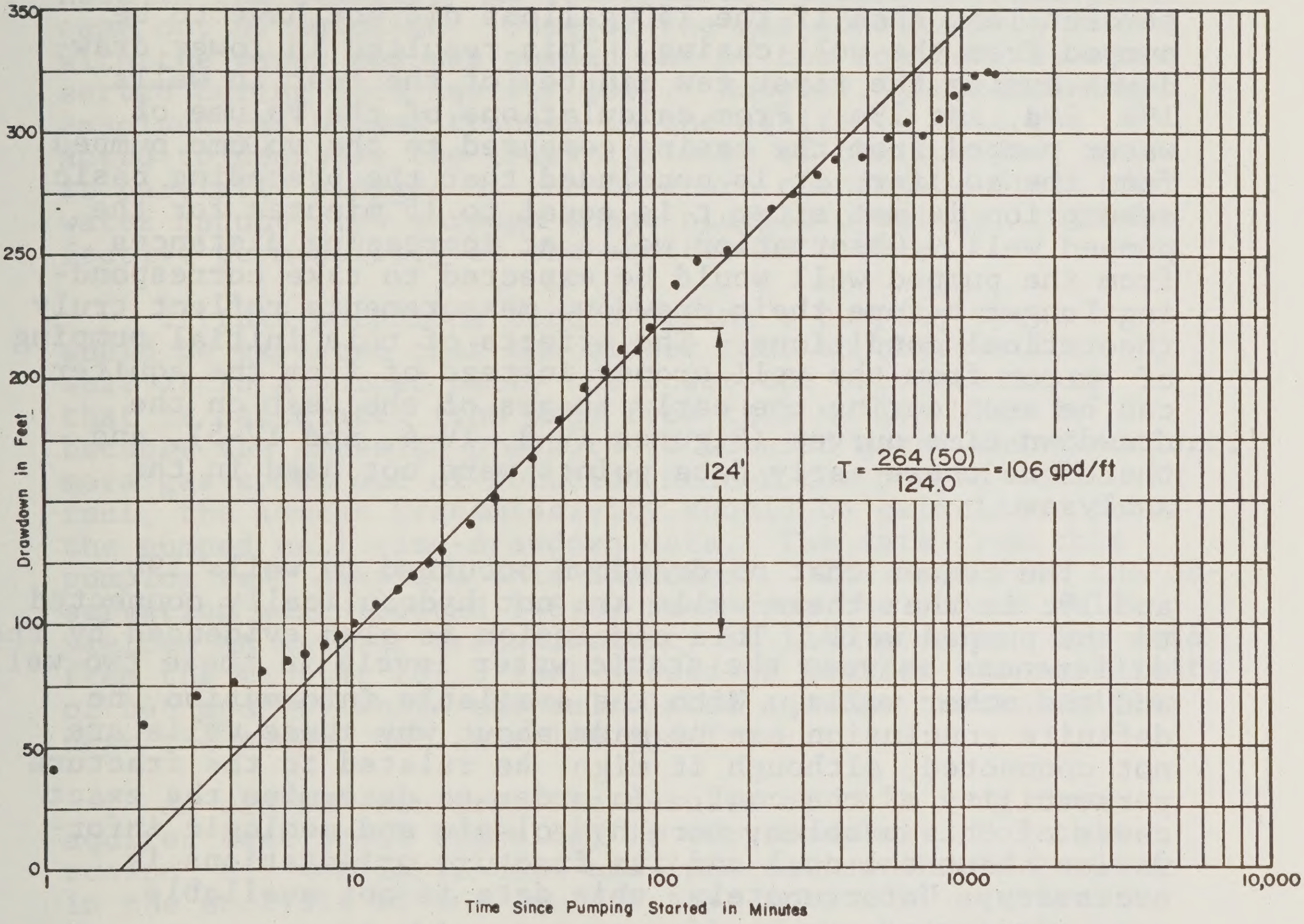


Figure IV-5. Drawdown Versus Time for Pumped Well (19a).

inside the well casing that is removed by pumping is negligible compared to the volume of water pumped from the aquifer. Until this assumption is satisfied, the data collected should not be used to determine the aquifer characteristics. During the first 10 minutes of this pumping test, approximately 150 gallons of water had to be pumped from the well proper. The total volume of water pumped in this period was 500 gallons. Therefore, the actual discharge from the aquifer was 30 percent less than if the 150 gallons did not have to be pumped from the well casing. This resulted in lower drawdowns during the first few minutes of the test in wells 19a, 19d, and 19e. From calculations of the volume of water pumped from the casing compared to the volume pumped from the aquifer, it is concluded that the preceding basic assumption is met after t is equal to 15 minutes for the pumped well. Observation wells at increasing distances from the pumped well would be expected to take correspondingly longer before their drawdown measurements reflect truly theoretical conditions. The effects of this initial pumping of water from the well proper instead of from the aquifer can be seen during the early stages of the test on the drawdown-time curves (Figures IV-3, IV-4, and IV-5), and therefore these early data points were not used in the analyses.

The reason that no drawdown occurred in wells 19b and 19c is that these wells are not hydraulically connected to the pumped well. This conclusion is also evidenced by the differences between the static water levels in these two wells and the other wells. With the available information, no definite conclusion can be made about why these wells are not connected, although it might be related to the fracture permeability of the coal. In order to determine the exact cause of this problem, more hydrologic and geologic information about the coal and its fracture orientations is necessary. Unfortunately, this data is not available.

The differences between the transmissivity and storage coefficient values for wells 19d and 19e can be partially explained by the anisotropic nature of fractured media, in this case, the coal bed. Three hydraulically connected observation wells are necessary in order to determine the maximum and minimum transmissivities and their directions. In this test, only two of the observation wells are hydraulically connected to the pumped well. Therefore, an anisotropic analysis could not be made.

Another portion of the differences in the aquifer characteristics between wells 19d and 19e, and also between these two wells and the pumped well, 19a, can be explained by the methane gas dissolved in the water from the coal aquifer, a not uncommon occurrence in the Powder River Basin. A mechanism by which the dissolved gas could affect pumping test data is as follows. Prior to the test, the gas in the water was under a pressure equal to the amount of artesian head on the aquifer. As the pumping test progressed, the pressure on the gas in the water decreased due to a lowering of the artesian head in the aquifer. As the pressure decreased, the gas came out of solution. Some of the gas continued to flow with the water and was pumped out of the aquifer, as observed during this aquifer test. However, the remaining exsolved gas became trapped in the aquifer. This gas acted to decrease the transmissivity of the aquifer, as it partially plugged up the fracture openings. Since the water cannot flow through these plugged openings, the effective permeability of the aquifer is reduced.

If this phenomena occurs during a pumping test, it would be expected that the closer that an observation well is to a pumped well, the lower the transmissivity that is calculated from data from this well. This is because the artesian pressure is lowered more, and therefore, more gas comes out of solution nearer the pumped well. In fact, the lowest transmissivity should be calculated from the pumped well time-drawdown data. The data from this pumping test displays this phenomena. The data from the observation well located 146.02 feet from the pumped well yielded an aquifer transmissivity of 1146 gpd/ft. The data from the well at 107.8 feet showed an aquifer transmissivity of 546 gpd/ft, while the calculated aquifer transmissivity near the pumped well was 106 gpd/ft.

As can be seen from the results of this long term aquifer test, coal hydrology is very complex. For this reason, all available data and information should be used in the analysis of any aquifer test in a coal aquifer. However, even if this is done, all of the hydrologic data collected during a pumping test cannot always be fully explained.

C. Recovery Tests on Monitoring Wells

In the past year, recovery tests on most of the wells in the monitoring network were performed. These recovery tests were performed on the wells with permanent pumps installed and on the flowing wells. The data from these tests was analyzed by a Theis recovery method (see Appendix G) for aquifer transmissivity. The calculated transmissivity for each well tested is shown in Figure IV-6, as are the transmissivities and locations of published aquifer tests.

It can be seen from this map that the aquifer characteristics can vary greatly over a short distance. Note for example the two published tests in Wyoming in T52N, R72W and T51N, R72W. These two tests were on the Wyodak coal seam. Each test consisted of a pumped well with several observation wells and was conducted with the same degree of efficiency. However, the transmissivity of this major aquifer varies by over an order of magnitude in a distance of approximately 1.5 miles.

In Figure IV-6, a few regions of relatively high or low transmissivity can be seen. In the southwestern portion of the study area, a region of moderately high transmissivity can be seen. In the southeastern portion, an area of low transmissivity is found. The area in Wyoming around T47N, R71W has relatively high transmissivity. It is anticipated that as more aquifer test data becomes available, more distinct areas of relatively high or low transmissivity can be determined for use in the computer model.

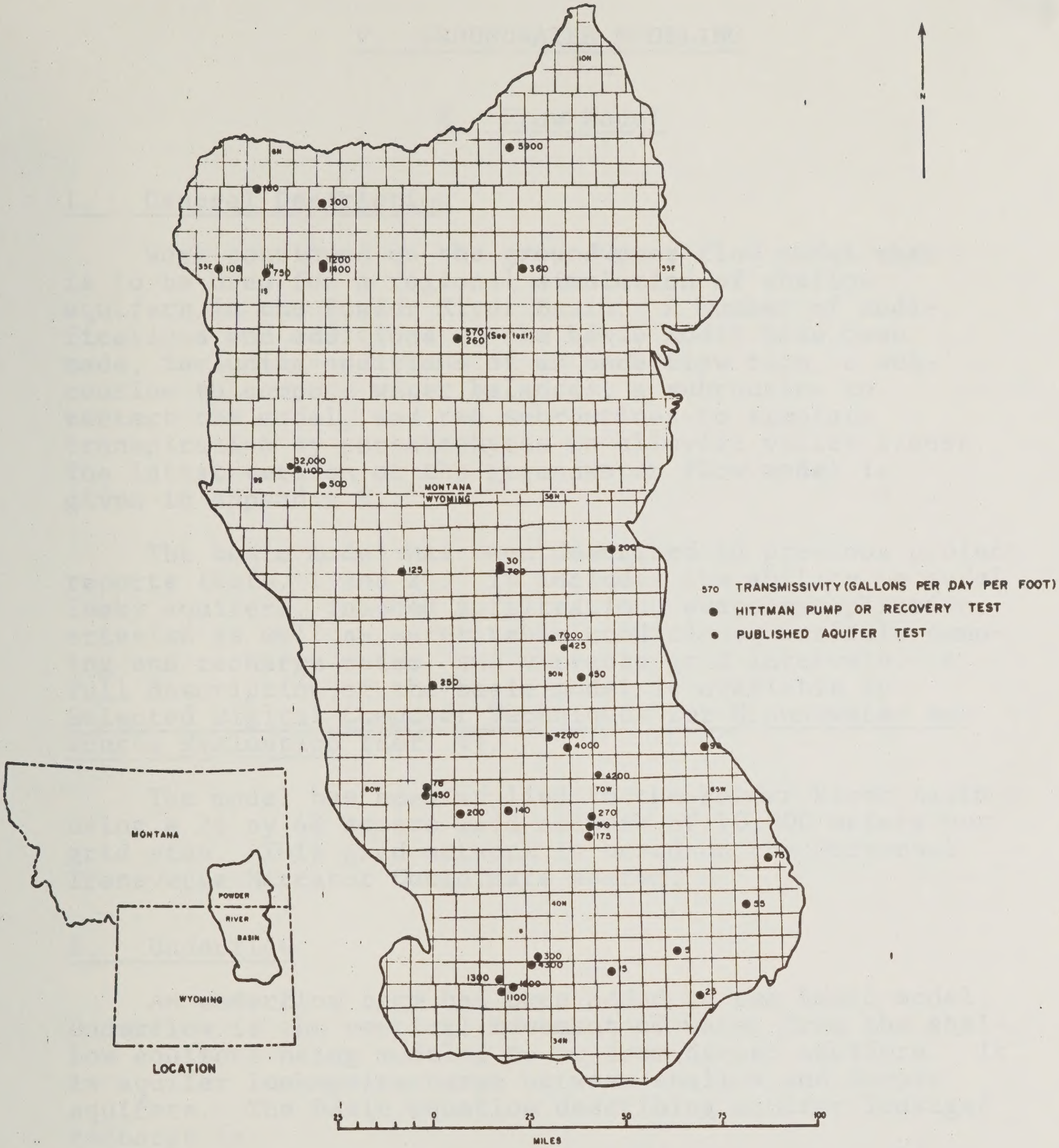

570 TRANSMISSIVITY (GALLONS PER DAY PER FOOT)
● HITTMAN PUMP OR RECOVERY TEST
• PUBLISHED AQUIFER TEST
N
10N
6N
35E
1N
1S
9S
55E
MONTANA
WYOMING
58N
50N
40N
34N
80W
70W
65W
5900
100
300
108
750
1200
1400
360
570
260 (See text)
32,000
4100
500
200
125
30
700
7000
425
250
450
4200
4000
98
4200
78
450
200
140
270
40
175
75
55
300
4300
1300
1600
1100
15
5
25
MONTANA
POWDER
RIVER
BASIN
WYOMING
LOCATION
25
0
25
50
75
100
MILES

Figure IV-6. Aquifer Transmissivity in the Powder River Basin

V. GROUNDWATER MODELING

A. Flow Model

1. General Description

Work continued on the groundwater flow model that is to be used for a regional simulation of shallow aquifers in the Powder River Basin. A number of modifications and additions to the basic model have been made, including additions of an underflow term, a subroutine to compute water balances, a subroutine to restart the model, and two subroutines to simulate transpiration by phreatophytes on alluvial valley floors. The latest version of the groundwater flow model is given in Appendix H.

The basic model has been described in previous project reports (Refs. 1 and 2). It includes the ability to model leaky aquifers, induced infiltration, evapotranspiration, artesian as well as water table conditions, variable pumping and recharge rates, and variable grid intervals. A full description of the basic model is available in Selected Digital Computer Techniques for Groundwater Resource Evaluation (Ref. 4).

The model has been applied to the Powder River Basin using a 28 by 48 square grid network of 10,000 meters per grid side. This grid network is based on the Universal Transverse Mercator Coordinate system.

2. Underflow

An underflow term has been added to the basic model. Underflow is the vertical movement of water from the shallow aquifers being modeled to or from deeper aquifers. It is aquifer leakage/recharge between shallow and deeper aquifers. The basic equation describing aquifer leakage/recharge is:

$$Q = (P/m) \Delta A$$

where

Q = leakage rate through the confining bed (gpd)

P = vertical hydraulic conductivity of the aquiclude (gpd/ft^2)

m = thickness of the aquitard (ft)

Δ = difference between the head in the aquifer and the head in the source bed underlying the confining aquifer (ft)

A = area of confining bed through which leakage takes place (ft^2)

In terms of the FORTRAN code that has been inserted in the model, the equation is:

$$\text{recharge/leakage} = R2(I,J) * \left[RH2(I,J) - H(I,J)\right]$$

where

R2(I,J) = ($^P/m$) A for node i,j (gpd/ft)

RH2(I,J) = head in deeper aquifer for node i,j (ft)

H(I,J) = head in modeled aquifer at node i,j (ft)

The Powder River Basin model is presently formulated as one continuous aquifer, extending from the land surface to 500 feet below ground. Thus, the lenticular nature of the aquifers in the Powder River is presently ignored. The top of the aquifer is set as the elevation of the land surface. The bottom of the aquifer is set 700 feet below a smoothed land surface. The smoothed land surface was created by putting the actual land surface through a triple-pass moving average algorithm. This smoothing was necessary so that the bottom of one aquifer node would not be higher than an adjacent aquifer node top. A discontinuity in the model is obviously undesirable. Continuity is also the reason for setting the bottom of the model aquifer 700 feet down, rather than 500.

The artificial nature of the aquifer bottom means that the underflow term is very important. An imaginary aquifuge was assumed by the basic model approximately 500 feet under the surface of the land. Since there may or may not be an impermeable layer at this depth, the underflow term is necessary to let water in and out through the bottom of the model.

In order to use the underflow term, one must specify the head in the deeper aquifers (RH2) and the vertical permeability (R2). The deep aquifer head was obtained by constructing from available data, a contour map of the water levels in the wells between 480 and 1020 feet deep in the Powder River Basin. This contour map is shown in Figure V-1. The locations of the wells used to produce this map are shown in Figure V-2. The data was obtained from various published data sources that were used in the creation of the computerized published well data file. The vertical permeability was set at 10^{-6} gpd/ft^3.

3. Water Balance

A subroutine was written to check the water balance of each node and for the model as a whole. This routine provides a check on the mathematical operation of the model and a method for determining where the true steady state water levels are.

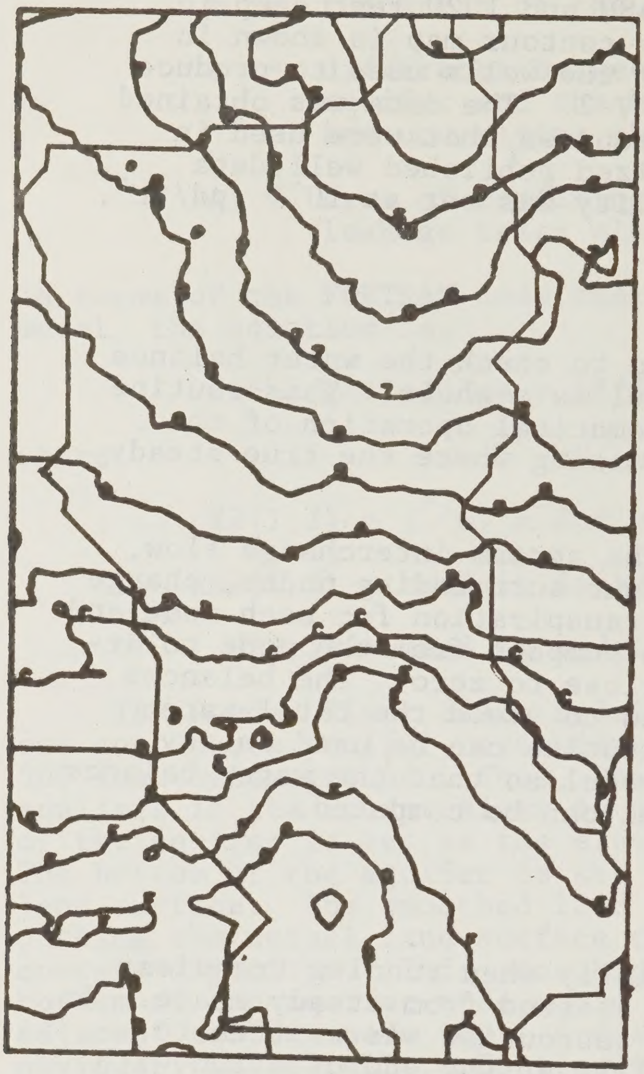
This routine computes the stream interchange flow, inflow or outflow from the four surrounding nodes, change in storage, underflow, and transpiration for each node and adds these quantities to the pumpage from the node to arrive at a number hopefully close to zero. The balances for each node are then summed to yield the total water balance of the model. The routine can be used on any rectangular section of the model so that the water balance for that portion of the model can be computed.

4. Restart Subroutine

It is desirable, especially when running transient analyses, that the model be started from steady state. In order to facilitate this, a subroutine was written to write out a new input data file at the end of a run with the final computed heads replacing the initial heads on the new input data file.

5. Evapotranspiration

In the arid regions of the west, transpiration by phreatophytes may be a significant consumptive use of groundwater. In the Powder River Basin, phreatophytes (cottonwoods and willows) are common in river bottom lands where groundwater is at a shallow depth. Measurements of consumptive use of water by cottonwoods have shown that groups of trees (corrected to 100 percent vegetative density) use up to 8.1 feet of water per year (Ref. 5). A consumptive



KEY

Symbol	Elevation(f
1	2000
2	2200
3	2400
4	2600
5	2800
6	3000
7	3200
8	3400
9	3600
A	3800
B	4000
C	4200
D	4400
E	4600
F	4800
G	5000
H	5200
I	5400
J	5600
K	5800

Figure V-1. Contour Map of Water Elevations in Wells Between 480 and 1020 Feet Deep in Powder River Basin

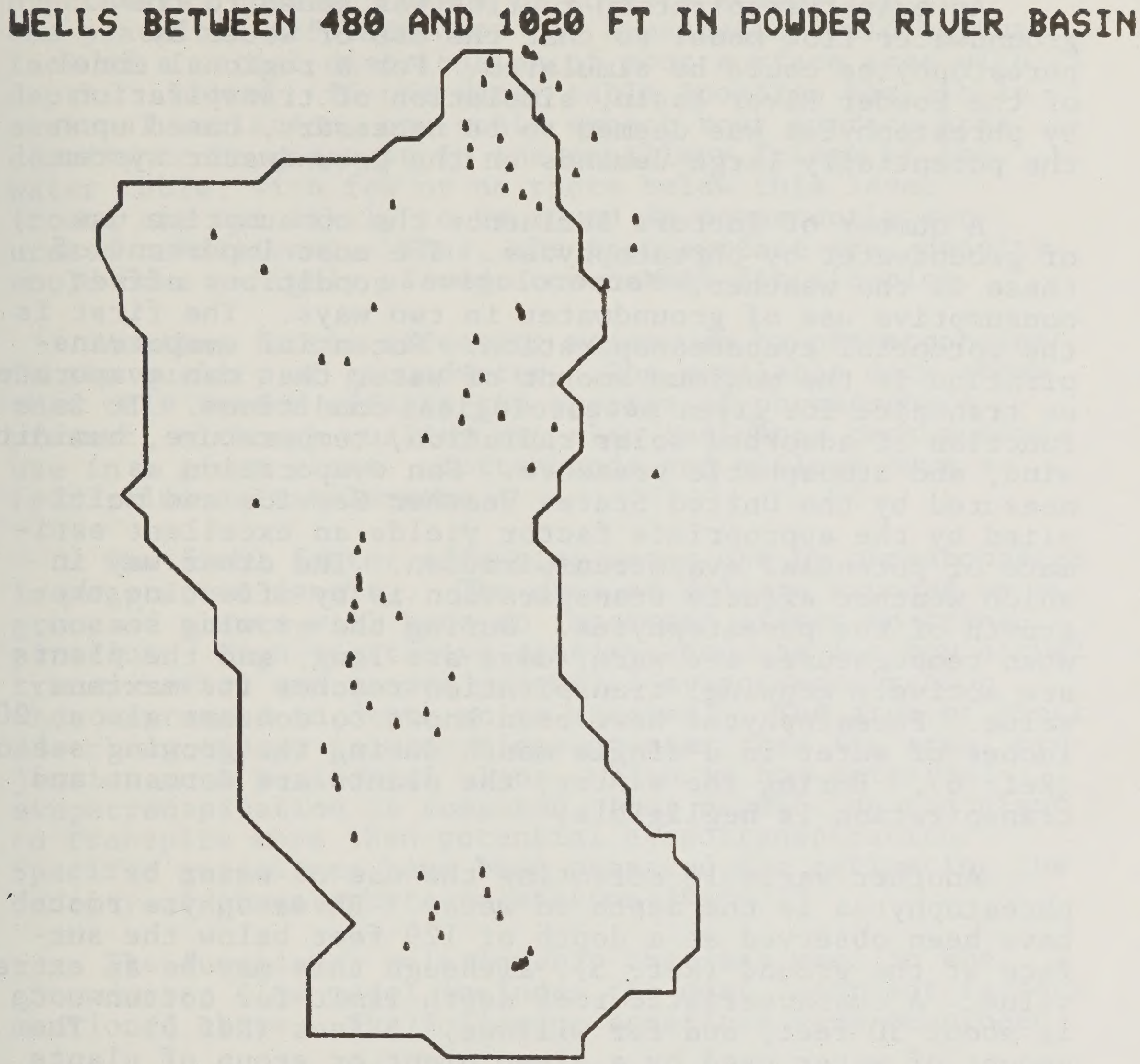

WELLS BETWEEN 480 AND 1020 FT IN POWDER RIVER BASIN

Figure V-2. Location of Data Points
Used to Construct Figure V-1

use of this magnitude will be significant on a regional scale.

An evapotranspiration routine was added to the groundwater flow model so that the use of water by phreatophytes could be simulated. For a regional model of the Powder River Basin, simulation of transpiration by phreatophytes was deemed to be necessary, based upon the potentially large demands on the groundwater system.

A number of factors influence the consumptive use of groundwater by phreatophytes. The most important of these is the weather. Meteorological conditions affect consumptive use of groundwater in two ways. The first is the potential evapotranspiration. Potential evapotranspiration is the maximum amount of water that can evaporate or transpire for given meteorological conditions. It is a function of adsorbed solar radiation, temperature, humidity, wind, and atmospheric pressure. Pan evaporation as measured by the United States Weather Service and multiplied by the appropriate factor yields an excellent estimate of potential evapotranspiration. The other way in which weather affects transpiration is by affecting the growth of the phreatophytes. During the growing season, when temperatures are warm, days are long, and the plants are actively growing, transpiration reaches its maximum value. Phreatophytes have been known to consume almost 20 inches of water in a single month during the growing season (Ref. 6). During the winter, the plants are dormant and transpiration is negligible.

Another variable affecting the use of water by phreatophytes is the depth to water. Phreatophyte roots have been observed at a depth of 129 feet below the surface of the ground (Ref. 5), although this may be an extreme value. A characteristic root depth limit for cottonwoods is about 30 feet, and for willows, 15 feet (Ref 5). The amount of water used by a given plant or group of plants is also dependent upon the depth to water. This phenomenon has been observed by many investigators. The functional relationship of this dependence is unknown, however. It could be theorized that the uptake of water by a single plant is dependent upon the surface area of root within the capillary fringe of the water table. If root surface area density has a normal distribution around some mean root depth, the relationship of root surface area below a depth will be an F distribution. Thus, the uptake of water with depth would follow an F statistic. This relationship should hold true for groups of plants as well, because for a range of plant sizes there will be a corresponding range of root areas. While certainly a plausible hypothesis, however, there is no data supporting it. One plausible refutation of the hypothesis would be the lack of a normal distribution of root surface area with depth. Indeed, if the water table location has little seasonal variation, one would expect root surface area density to be greatest in the capillary fringe of the water table, with few or no roots below this level (roots are not likely to be found in permanently saturated conditions). Thus, the root surface area density would have a highly skewed, non-normal distribution.

Another factor affecting water use by phreatophytes is the quality of groundwater. The available data shows that this factor affects the species of phreatophyte present, although quality may also influence consumptive use in a given plant. Cottonwoods and willows have a fairly low salt tolerance.

One final factor affecting water use by phreatophytes is vegetative density. The area of foliage exposed by a group of plants will have an important effect on transpiration. High vegetative density accounts for how actual transpiration can exceed potential evapotranspiration when expressed in depth units (inches). The area of plant adsorbing energy is many times greater than its areal projection on a horizontal plane, which is how potential evapotranspiration is computed, thus permitting the plant to transpire more then potential evapotranspiration. Specific guidelines have been prepared for estimating the density of phreatophyte vegetation (Ref. 7).

The functional relationship that was used in the groundwater flow model includes the most important factors mentioned above. The following equations were developed:

$$QET = ACRES \times DEN \times ET \times GR \times K \quad \text{for } H \geq RH$$

$$QET = ACRES \times DEN \times ET \times GR \times K \times (H-RD) \quad \text{for } H < RH \text{ and } H \geq RD$$

$$QET = 0 \quad \text{for } H < RD$$

where

QET = actual transpiration by phreatophytes (gpd)

ACRES = acreage of phreatophytes (acres)

DEN = density of phreatophyte vegetation

GR = growth factor, this factor varies each month to account for plant growth. It varies between 0 and 1 and will be very small in winter, and up to 1 in the summer.

ET = potential evapotranspiration (in./day)

K = conversion factor to account for differences in units

RH = upper limit of depth dependence of transpiration. When the water table is above this limit, QET is equal to its maximum value (ft).

RD = lower limit of transpiration, probably equal to the lower limit of root depth (ft)

H = elevation of water table (ft).

The relationship between transpiration and depth was assumed to be linear. Figure V-3 shows the form of this equation. There is a depth (RD) below which no transpiration occurs; between depths RD and RH, transpiration is a linear function of depth; above depth RH, transpiration is equal to its maximum value.

B. Quality Model

Work continued on the development of a groundwater quality model. A program has been written to smooth the output from the basic model. The basic model has also been modified so that the parameters subject to first order decay can be modeled. The groundwater quality model is given in Appendix I.

1. Basic Model

The basic groundwater quality model has the capability

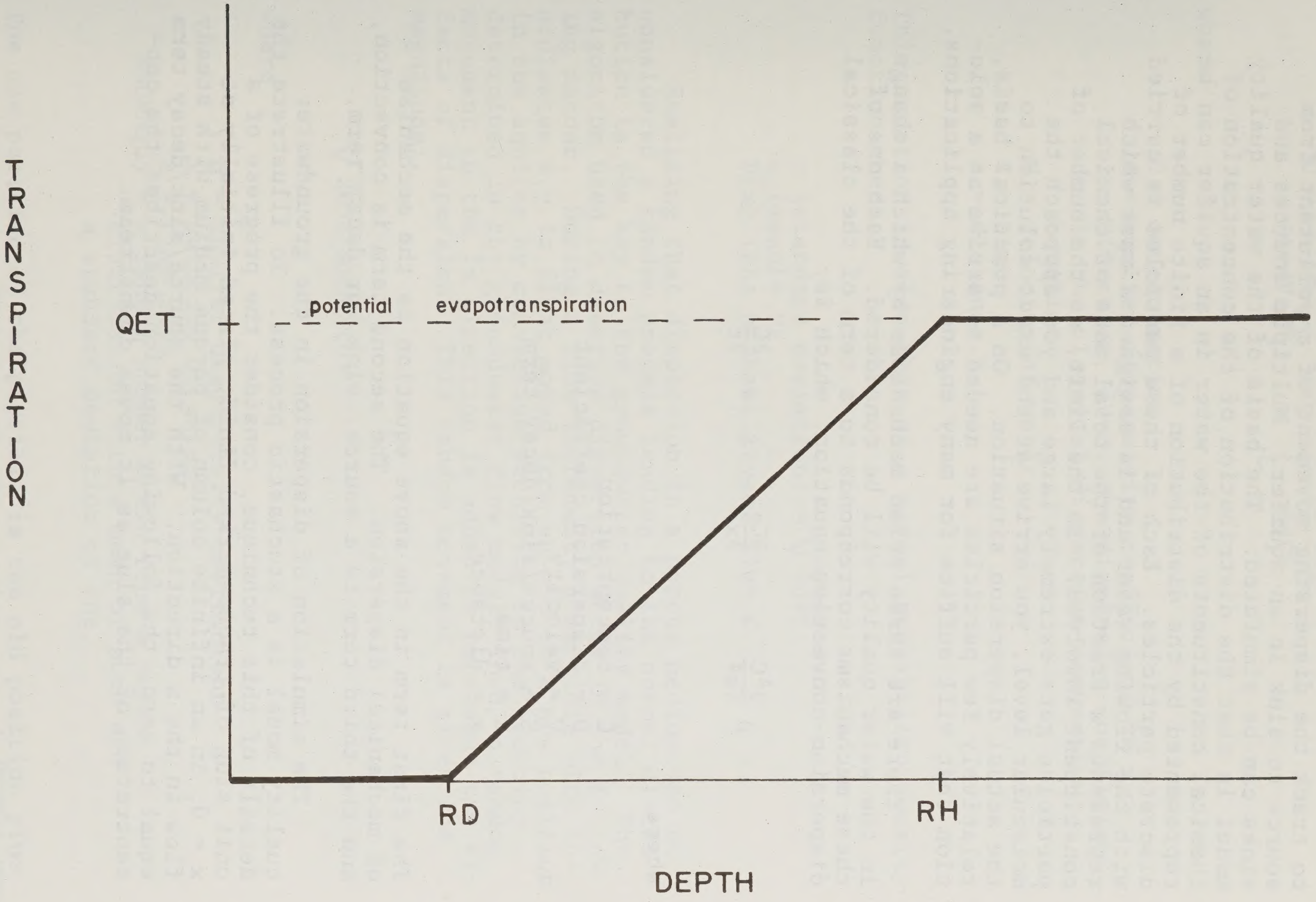


Figure V-3. Assumed Relationship between Transpiration and Depth

to track the dispersing movement of a pollutant from source to sink in an aquifer. Multiple sources and sinks can be simulated. The basis of the water quality model is that the distribution of the concentration of chemical constituents of the water in an aquifer can be represented by the distribution of a finite number of discrete particles. Each of these particles is carried with the flowing water and is assigned a mass which represents a fraction of the total mass of chemical constituent involved. In the limit, as the number of particles gets extremely large and you approach the molecular level, you arrive at the exact solution to the actual dispersion situation. On a practical basis, relatively few particles are needed to arrive at a solution that will suffice for many engineering applications.

There are three prime mechanisms by which a change in the water quality will be considered. Each one of these mechanisms corresponds to a term of the classical dispersion-convection equation, which is:

$$D \frac{\partial^2 C}{\partial x^2} + V \frac{\partial C}{\partial x} + S = \frac{\partial C}{\partial t}$$

where

C = concentration
D = dispersion coefficient
V = velocity
S = source/sink/decay term
t = time
x = distance.

The first term in the above equation is the mechanism of mechanical dispersion. The second term is convection, and the third term is a source, sink, or decay term.

The simulation of dispersion in the groundwater quality model is a stochastic process. To illustrate the details of this technique, consider the progress of a unit slug of tracer-marked fluid, placed initially at x = 0, in an infinite column of porous medium with steady flow in the x direction. With the source/sink/decay term equal to zero, the following equation describes the concentration of the slug as it moves downstream.

$$C = \frac{1}{(4\pi dVt)^{\frac{1}{2}}} \exp\left[-\frac{(x-Vt)^2}{4dVt}\right]$$

where

C = concentration
d = aquifer dispersivity coefficient in x direction; dV=D, the dispersion coefficient in the classical dispersion-convection equation
V = velocity of water
t = time
x = distance.

This equation is also that of a normal probability density function where:

σ (standard deviation) = $\sqrt{2dVt}$
μ (mean) = Vt
P(x) (the probability of x) = C

Realizing that dispersion in a porous medium can be considered a random process tending to the normal distribution is the key to the groundwater quality model. The algorithm used to describe dispersion works in the following manner. During a time increment, a particle with coordinates x,y is first moved from an old to a new position in the aquifer by convection according to the veolcity determined in the groundwater flow model. Then, a random movement in the $\pm$x direction is added to represent the effects of dispersion. This random movement is given the magnitude:

$$\sqrt{2dV\Delta}*ANORM(0)$$

where

d = aquifer dispersivity coefficient
V = velocity of water
Δ = time step
ANORM(0) = a random number drawn from a normal distribution with a mean of zero and a standard deviation of one.

The new position of the particle is the old position plus a convective term (VΔ) plus the dispersion term ($\sqrt{2dV\Delta}$*ANORM(0)).

Now, if the above experiment is repeated with numerous particles, all having the same initial position and convective term, the new positions of the particles could be plotted. The resulting plot would approximate a normal density distribution and the solution to the classical dispersion equation.

The convective mechanism of the groundwater quality model involves moving the discrete particles according to the velocity vectors. Node velocity is computed from the head distribution computed in the groundwater flow model using the equation:

$$V = \frac{PI}{7.48\rho}$$

where

V = velocity (ft/day)
P = permeability (gpd/ft^2)
I = hydraulic gradient (dimensionless)
ρ = effective porosity (dimensionless).

Actual velocities used to move the particles are interpolated from nodal velocities. The particles are allowed to move a maximum of 0.2 grids before a new velocity is reinterpolated.

A variety of source and sink functions are present in the groundwater quality model and others could be added. There are two methods of originating particles in the model. The first is analogous to an instantaneous injection at a point or over an area. The second is a continuous source of constant concentration. One type of sink is presently allowed in the model. The sink function removes all particles coming within one grid of the sink nodes. Sink concentrations are also computed.

2. Smoothing

Due to the fact that the quality model functions by moving discrete particles in a stochastic manner, the output from the quality model often has a "lumpy" or uneven appearance. For some applications, this is of little or no concern, but for others, it is desirable to have smooth curves of pollutant concentrations. Smooth curves can be obtained in two ways; first, by increasing the number of discrete particles in the model, and second, by smoothing the output with some type of curve smoothing routine. Increasing the number of particles to the point where a smooth concentration curve would be obtained is an expensive option; computer costs are roughly proportional to the number of particles in the model. Therefore, a computer program to smooth the output from the model was written.

There are a number of ways the curve smoothing could be accomplished. A moving average in time, a moving average in two-dimensional space, or a Fourier transform, low pass filter may be used to filter the data, but one of the most effective smoothing methods is the use of cubic spline smoothing.

The smoothing routine used was one from the subroutine library of Boeing Computer Services' EKS system. Cubic spline smoothing involves fitting a series of cubic polynomials through the data points, as in cubic spline interpolation. Then the cubic splines are computed through the points adjacent to the point of interest, and this point is moved toward the cubic spline. This procedure takes place for each point, for a number of passes. Trials were run to select the optimum number of passes.

The smoothing program computes the maximum point movements based upon the mass of one discrete particle. The cubic spline smoothing routine is called to smooth the rows, then the columns, and then the rows and columns again. This procedure yields a fairly smooth and representative curve.

3. Decay

In order to permit the simulation of radioactive substances in other pollutants subject to first order decay, a decay option was added to the quality model. The basic first order decay equation is:

$$\frac{dC}{dt} = \lambda C$$

where

C = concentration
t = time
λ = rate of decay in reciprocal time.

This equation can be integrated to:

$$C = C_o \exp(-\lambda t)$$

This final equation was added to the overall model. Data collected from the field water quality monitoring program will be used in this decay subroutine to further define the characteristics of the groundwater quality in the Powder River Basin.

C. Model Verification

The validity of the groundwater flow and quality models was tested by running the models on hypothetical situations for which theoretical solutions are available. This provides a check on the programming and installation of the models on the computer.

A hypothetical case was devised to check both the flow and quality models. The case was one involving a pumped well (sink) and stream recharge (source) in a confined, infinite aquifer. A diagram of the hypothetical case is shown in Figure V-4.

1. Flow Model

The flow model was verified for both the transient and steady state solutions using the hypothetical case shown in Figure V-4. An infinite aquifer was simulated by increasing the grid intervals at the outer edges of the grid network. The grid intervals starting from the well moving outward in all directions were 1000 feet for eight grids, then 2000 feet, 8000 feet, 16,000 feet, 32,000 feet, 64,000 feet, and 128,000 feet. Thus, an infinite aquifer was approximated. The other input parameters are shown in Figure V-4.

Figure V-5 shows the results of running the flow model on the hypothetical case. The theoretical solution was obtained using the Theis equation and a recharging image well. Excellent agreement is seen between the theoretical and model drawdowns.

2. Water Quality Model

The water quality model was verified using the same hypothetical case (Figure V-4). The stream was assumed to be a constant source of pollution with a pollutant concentration of 200 mg/l. The only pollutant sink was the

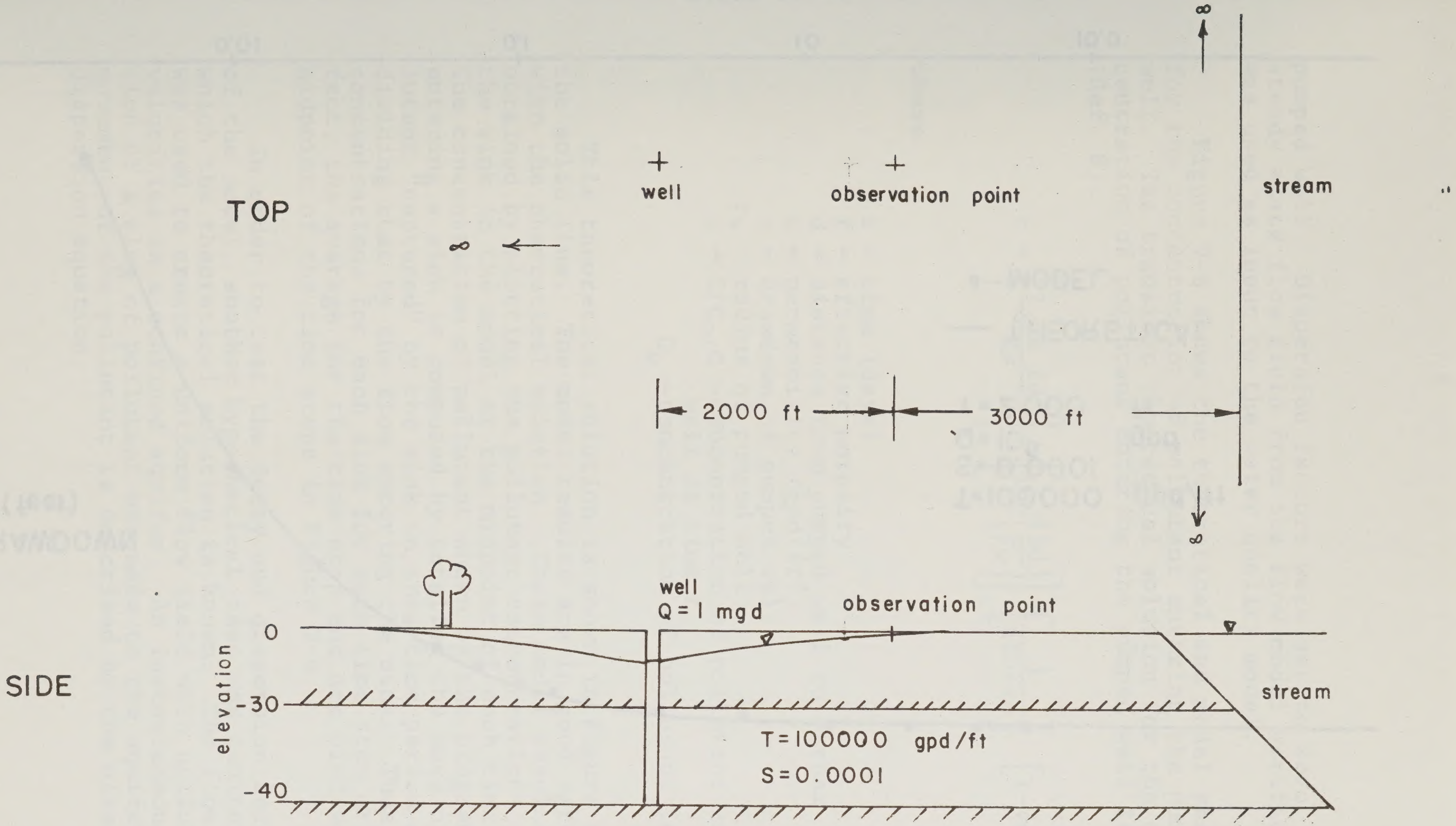

TOP
∞
well
observation point
stream
2000 ft
3000 ft
∞
∞
SIDE
elevation
0
-30
-40
well
Q = 1 mgd
observation point
stream
T = 100000 gpd/ft
S = 0.0001

Figure V-4. Hypothetical Case for a Theoretical Verification of the Model

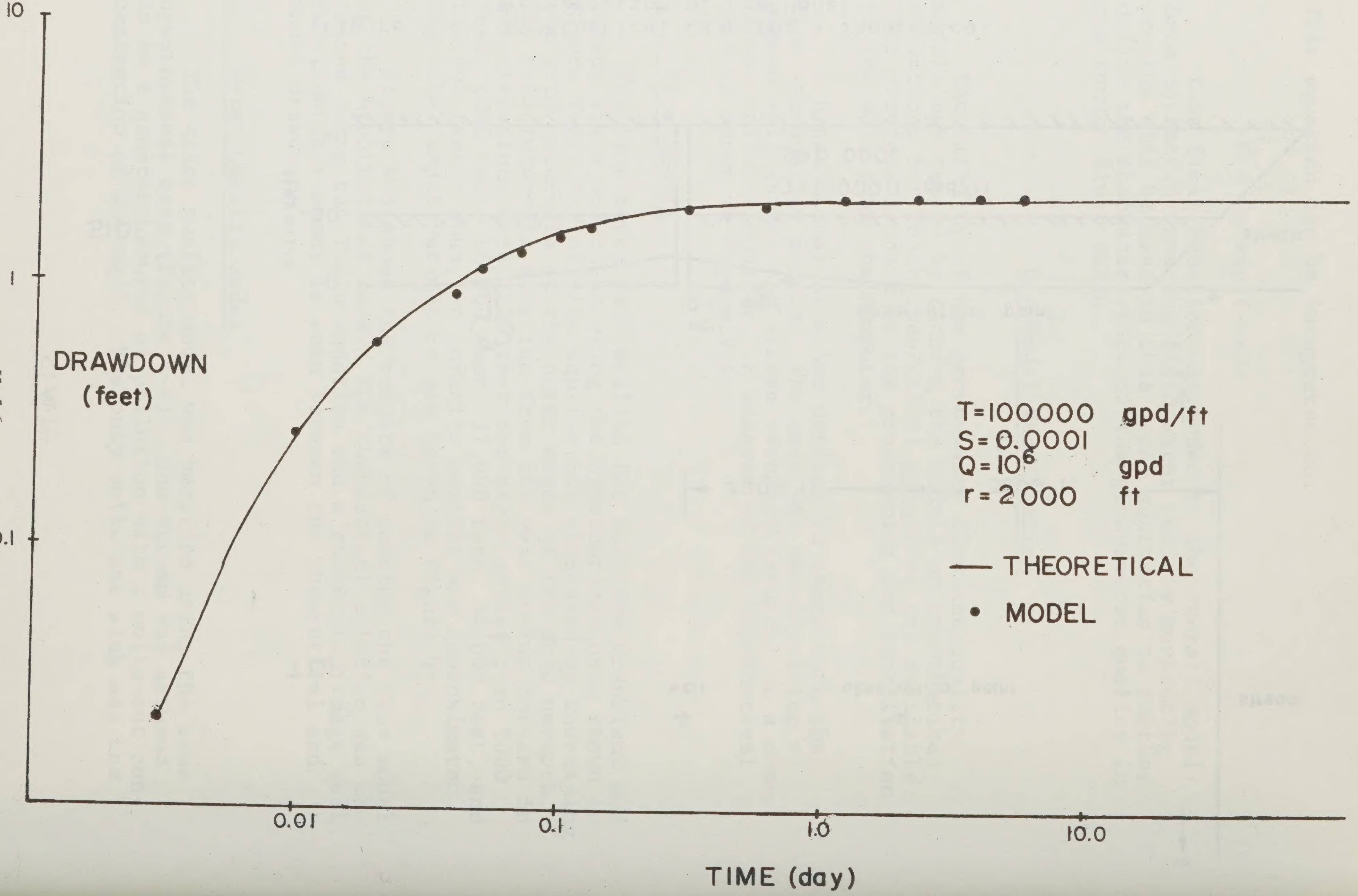


Figure V-5. Theoretical and Model Drawdowns

pumped well. Dispersion factors were set to zero. The steady state flow field from the flow model verification was used as input to the water quality model.

Figure V-6 shows the theoretical and model results for the concentration of pollutant entering the pumped well. The transient theoretical solution for the concentration of pollutant entering the pumped well is (Ref. 8):

$$t = \left[\frac{7.48\ fd^2}{Ks}\right] \left[\ln\left(\frac{2d}{r_w}\right)\right] \left[\frac{1}{\sin^2 \pi c}\right] \left[1-(\pi c)\cot \pi c\right]$$

where

t = time (days)
f = effective porosity
d = distance from pumped well to stream (ft)
K = permeability (gpd/ft^2)
s = drawdown of pumped well
r_w = radius of pumped well
$c = C/C_o$; C = concentration of pollutant entering well at time t
C_o = concentration of pollutant in stream

This theoretical solution is shown in Figure V-6 by the solid line. The model results are in good agreement with the theoretical solution. These model results were obtained by plotting the pollutant concentrations entering the sink in the model at the midpoint of each time step. The concentration of pollutant shown by the program to be entering a sink is computed by totaling the mass of pollutant "captured" by the sink in that time period and dividing that by the flow entering the sink. Thus, the concentrations for each sink for each time step are, in fact, the average for the time step and are plotted at the midpoint of the time steps in Figure V-6.

In order to test the decay and dispersion features of the model, another hypothetical case was devised for which the theoretical solution is known. The flow model was used to create a uniform flow field with uniform velocities in a confined aquifer. An instantaneous injection of a slug of pollutant was made to the aquifer. The movement of the pollutant is described by the classical dispersion equation:

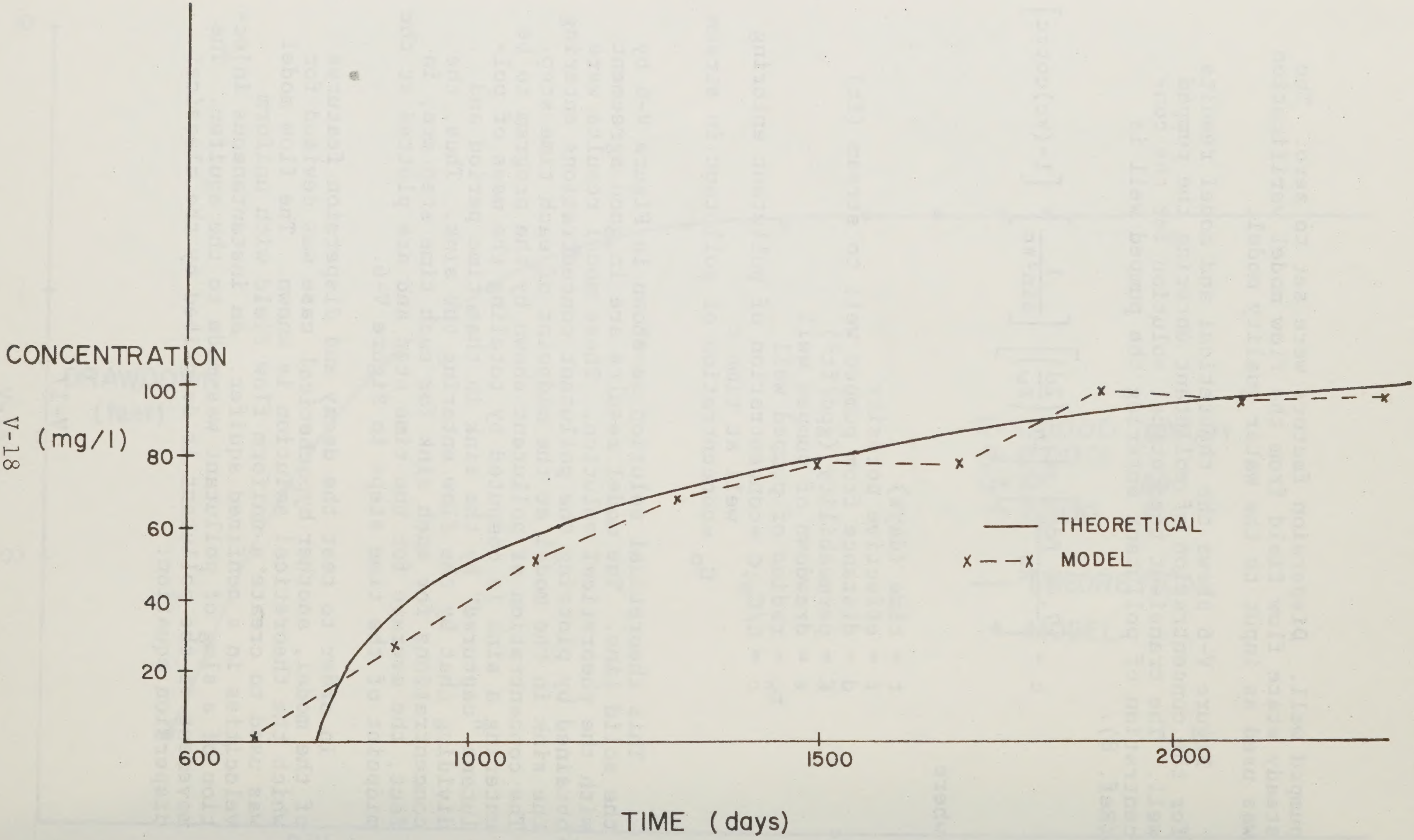


Figure V-6. Theoretical and Model Concentrations of Pollutant Entering the Pumped Well

$$C = \frac{m}{4\pi ntv\sqrt{(d_x d_y)}} \exp\left[\frac{-(x-vt)^2}{4d_x vt} - \frac{y^2}{4d_y vt} - \lambda t\right]$$

where

C = concentration of pollutant (lb/ft^3)
m = mass of pollutant injected at $t=0$ (lb/ft)
n = actual porosity
t = time (days)
v = seepage velocity (ft/day)=Darcy velocity x effective porosity
d_x, d_y = diffusivities (ft)
λ = decay coefficient in reciprocal days.

Figure V-7 shows the model results and theoretical results for the convection and dispersion of an instantaneous slug of pollutant injected into a uniform velocity field. The decay coefficient was equal to zero. The model and theoretical results are in good agreement. Actually, the smoothing algorithm has made the results worse for this case; the peak was flattened out below the theoretical peak. The unsmoothed output corresponded to the theoretical almost exactly.

Figure V-8 shows the model results and theoretical results for the same case shown in Figure V-7, but with a much higher dispersion coefficient. Figure V-8 also shows the sensitivity of the PM parameter, which determines the number of particles in the model. As the number of particles is increased, the accuracy of the model increases. The tradeoff between cost and accuracy must be made for each individual problem, however, enough particles must always be present so that the results are not misleading. One rule of thumb that can be used is that the number of particles in a grid of interest should always be two digits.

The first order decay feature of the model was tested with the classical dispersion equation also. The case shown in Figure V-8 was used, except a decay rate of 0.0001 days $^{-1}$ was added. Figure V-9 shows the theoretical and model results for the convection and dispersion of a pollutant subject to first order decay after instantaneous injection in a uniform velocity field. There is good agreement between the theoretical and model curves. Once again, accuracy could have been increased by increasing the number of particles, but at the cost of using more computer time.

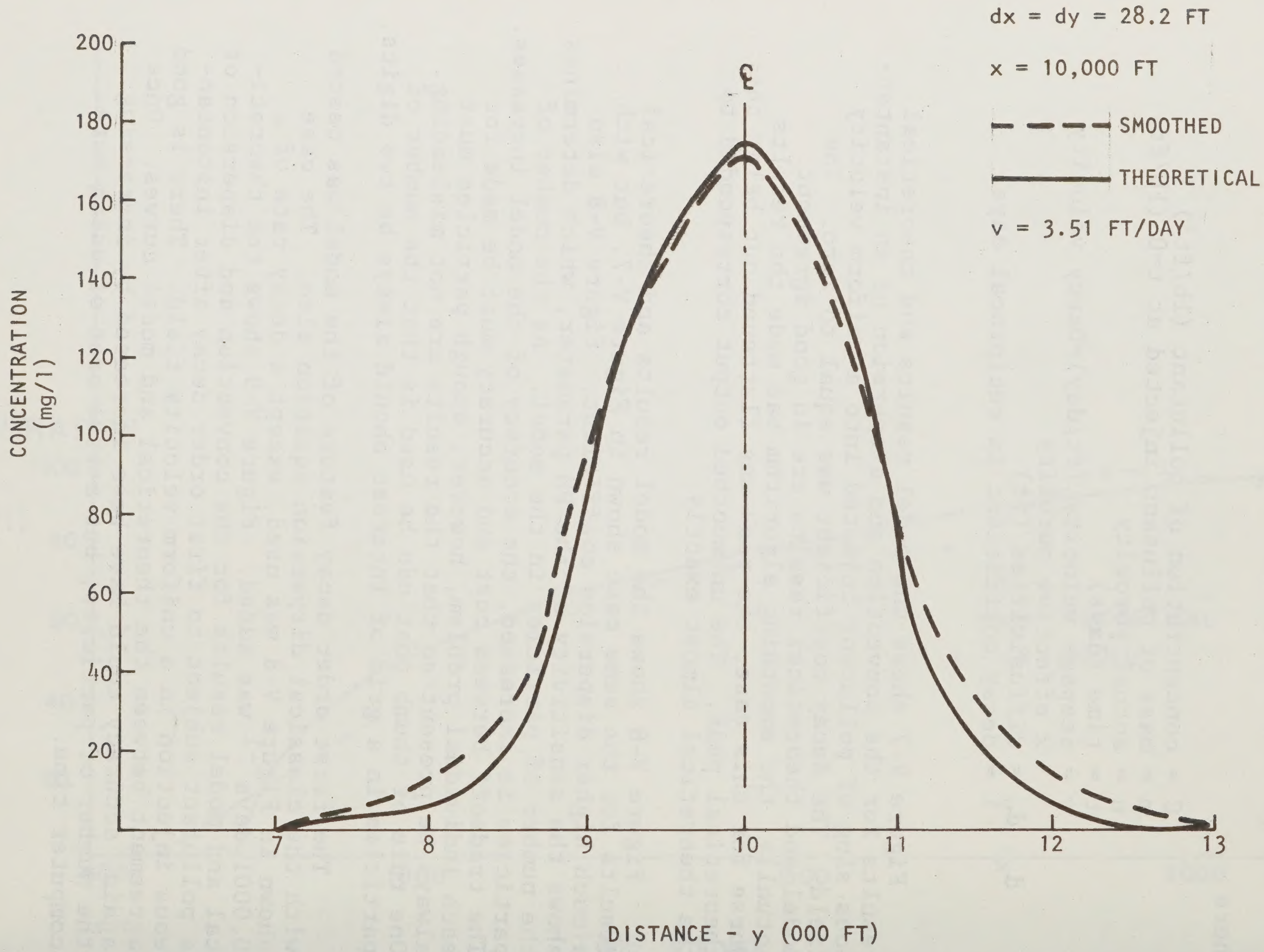


Figure V-7. Model versus Smoothed Theoretical Results for Convection and Dispersion Example

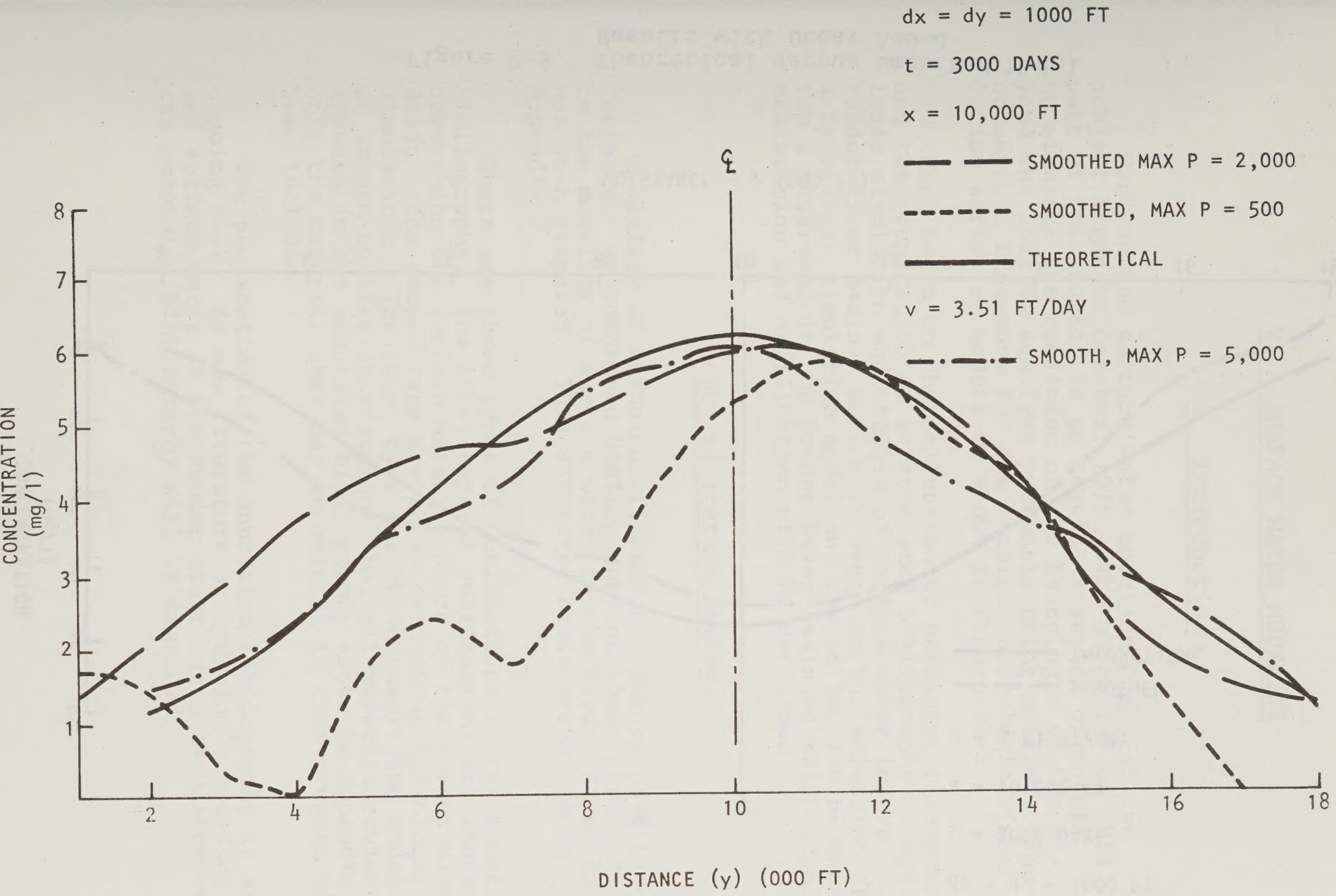


Figure V-8. Model versus Theoretical Results for High Dispersion and Different Numbers of Particles

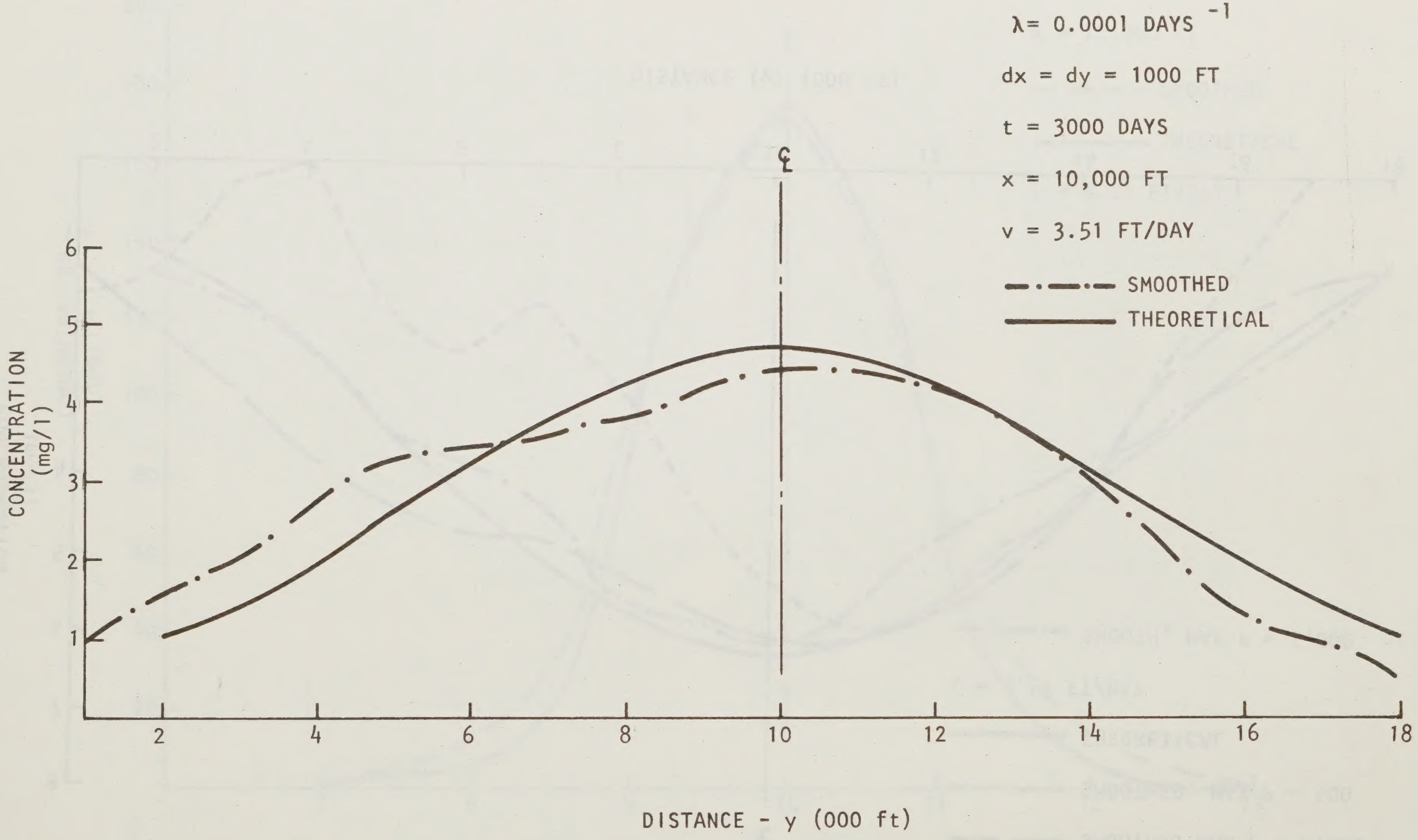


Figure V-9. Theoretical versus Smoothed Model Results with Decay Added

VI. SURFACE WATER MODELING

A. Introduction

Work on the surface water modeling phase of the project began in October, 1978. The objective of this part of the project is to develop a series of models to simulate the remainder of the hydrologic system beyond the shallow aquifers presently being modeled. The conceptual framework for the complete hydrologic simulation series of models is shown in Figure VI-1.

Work began on the collection of pertinent literature and the preparation of an annotated bibliography on hydrologic simulation and studies of surface water in the Powder River Basin. Work also began on the selection of a hydrologic simulation model and the collection of data for a watershed in the Powder River Basin on which model calibration and verification will be performed.

B. Literature Review

A variety of technical literature sources have been reviewed. An annotated bibliography of those pertinent to the modeling of surface water in the Powder River Basin has been prepared. This annotated bibliography is in Appendix J.

There are three types of publications in the annotated bibliography. The first type of publications are those describing the surface water resource of the Powder River Basin. The second type are those describing hydrologic simulations. The third type are those describing models of stream-aquifer interaction. Not all material reviewed appears in the annotated bibliography shown in Appendix H, only the material that may be helpful to this program has been included.

The preparation of the annotated bibliography is an ongoing task. As new literature on hydrologic modeling and surface water of the Powder River Basin is discovered, the annotated bibliography will be expanded.

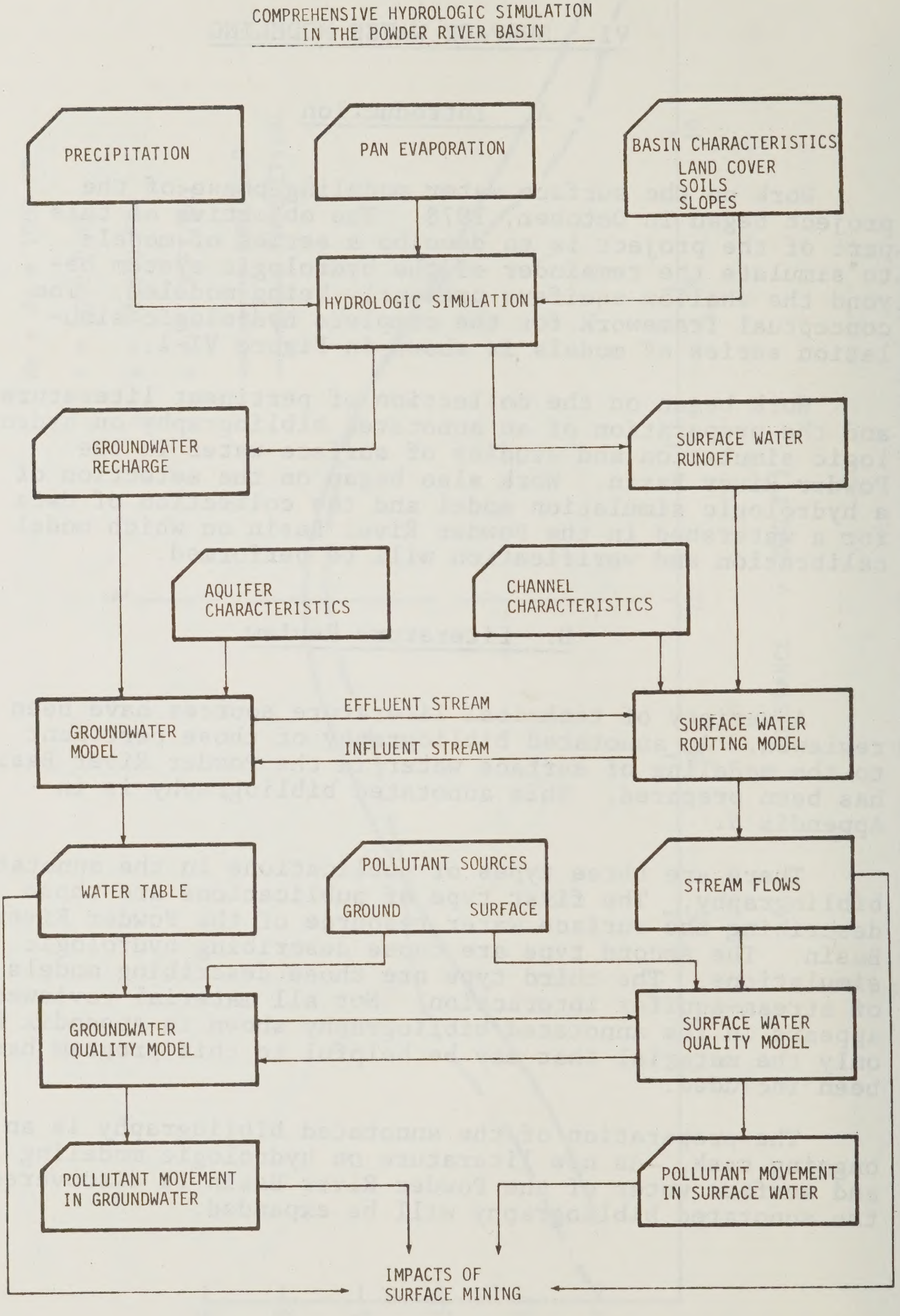

COMPREHENSIVE HYDROLOGIC SIMULATION
IN THE POWDER RIVER BASIN
PRECIPITATION
PAN EVAPORATION
BASIN CHARACTERISTICS
LAND COVER
SOILS
SLOPES
HYDROLOGIC SIMULATION
GROUNDWATER
RECHARGE
SURFACE WATER
RUNOFF
AQUIFER
CHARACTERISTICS
CHANNEL
CHARACTERISTICS
GROUNDWATER
MODEL
EFFLUENT STREAM
INFLUENT STREAM
SURFACE WATER
ROUTING MODEL
WATER TABLE
POLLUTANT SOURCES
GROUND
SURFACE
STREAM FLOWS
GROUNDWATER
QUALITY MODEL
SURFACE WATER
QUALITY MODEL
POLLUTANT MOVEMENT
IN GROUNDWATER
POLLUTANT MOVEMENT
IN SURFACE WATER
IMPACTS OF
SURFACE MINING

Figure VI-1. Complete Hydrologic Simulation Framework

C. Selection of a Surface Water Model

One of the major problems in hydrology is defining the relationship of precipitation to runoff, infiltration, and recharge. This problem can be solved using loss rates and unit hydrographs, however, with the advent of high speed digital computers, a new approach is possible. This approach is simulation, that is, the representation of the hydrologic system on the computer so as to imitate the behavior of the natural system. It is based upon the concept that there are basic hydrologic functions, such as infiltration, evapotranspiration, runoff, and groundwater recharge, that are common to all watersheds. By adjusting the hydrologic functions, any watershed can be realistically simulated. All hydrologic simulation models are based on this concept. Another important concept is the use of water budgeting over small time intervals. All hydrologic simulation models keep a water budget by applying each hydrologic function over a small time interval, typically an hour.

The equations of hydrologic simulation models are generally not new. What is new is the application of these equations on very small time intervals (hours) on large masses of data (years). In this manner, a realistic model of a watershed is created. Once the model is calibrated, it can be used for flood studies, water quality studies, and/or water availability studies.

Two hydrologic simulation models were evaluated for use in the Powder River Basin. The first of these is the Agricultural Research Service (ARS) USDAHL-75 Model of Watershed Hydrology. This model was developed for the simulation of small agricultural watersheds. The second is the Agricultural Runoff Management Model. This model is a revision of the Stanford Watershed Model, the first and best known hydrologic simulation model. It is able to simulate a variety of nonpoint source pollutants emanating from small agricultural watersheds.

1. The Agricultural Research Service USDAHL-75 Model

a. General. The ARS USDAHL-75 Model of Watershed Hydrology was written for an IBM 360-65 computer using FORTRAN programming language. After some modification, the program was able to run on Boeing Computer Service's CDC Cyber 175 computer. It requires 8.1 CP seconds compilation time and 7.2 CP seconds execution time with a total job processing cost of approximately 163 CCUS for a one-year hydrologic simulation.

The program is composed of 14 distinct subroutines in addition to the MAIN routine. With the exception of the POLLUT subroutine, all of the subroutines are required for complete hydrologic simulation. Since the function of each subroutine is quite distinct, changes and modifications can be made easily. For example, subroutine ETCALC computes evapotranspiration and subroutine EVAP computes evaporation. A short description of each subroutine is given in Table VI-1, and a flow diagram for the program is given in Figure VI-2.

The program is relatively easy to use. Extensive use of comment cards such as the definition of all variables in COMMON make the program easy to follow. Comments at the beginning of each subroutine describe its function and further clarifications are made at important computational steps.

The model uses two input files and five output files. The user has a great deal of control over what output is printed or saved. By the use of the proper job control language, storm hydrograph output in output file IHYD can be printed out or stored on a disk file.

b. Precipitation and Snowmelt. Precipitation data input to the model can be either in the form of rain or the water equivalent of snow. The data can be entered at any regular time interval or at breakpoints on the mass curve. The time increment should not exceed 24 hours for any precipitation period and should not exceed two months for any period of no precipitation. Subroutines ETCALC, EVAP, SUBSUR, INFIL and PEROUT are called for each increment of time in precipitation data.

Snowfall is designated by an "S" following its water equivalent in the precipitation input. Snowmelt is determined by the following equation:

TABLE VI-1. DESCRIPTION OF THE ARS MODEL SUBPROGRAMS

Subroutine	Description
MAIN	Calls all the subprograms, controls time step, initializes some variables, defines all variables in common, and starts and stops run.
DATA	Prepares breakpoint input data for model use.
DAYS	This subroutine calculates the number of days from one date to another and makes sure there is no error in either of the dates.
ETCALC	Calculates evapotranspiration (potential and actual).
EVAP	Calculates evaporation directly from free water and on soil surface.
INFIL	Calculates the volume of infiltration into a zone and the amount of precipitation excess for each increment of rainfall.
INIT	Initializes values for variables.
LANUSE	Calculates the growth index curves based on mean temperatures and tillage practice.
OUTPUT	Prints daily summary.
PARAMS	This subroutine reads all the input parameters and initializes some of the values.
PEROUT	Routes precipitation excess overland to the next zone.
POLLUT	Prints summaries needed if soil erosion and chemical transpost are to be calculated by the user.
ROUTE	Channel routing subroutine.
SUBSUR	Calculates downward and lateral flow for each layer.
SUMRY	Prints annual output.

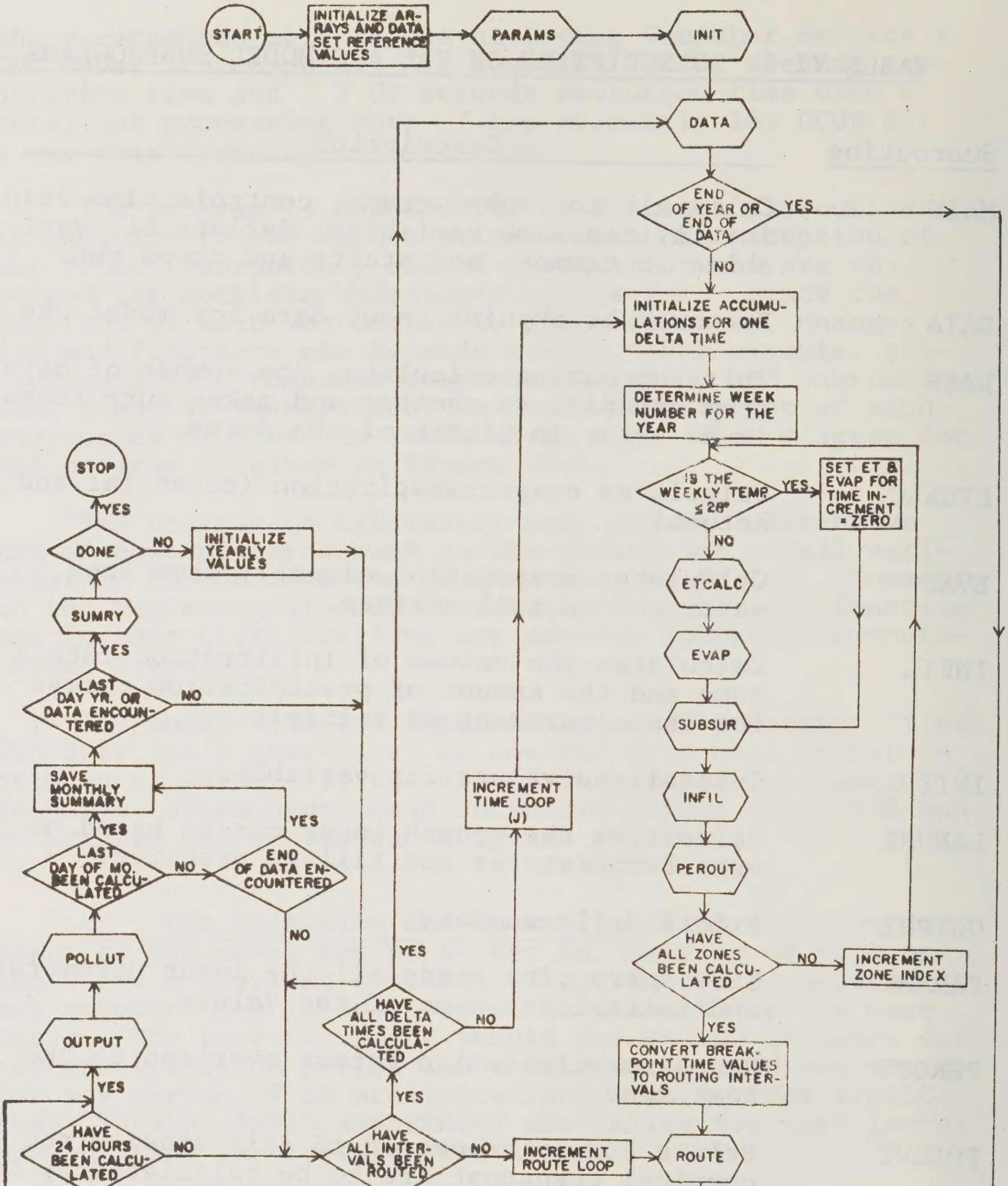

START
INITIALIZE ARRAYS AND DATA SET REFERENCE VALUES
PARAMS
INIT
DATA
END OF YEAR OR END OF DATA
YES
NO
INITIALIZE ACCUMULATIONS FOR ONE DELTA TIME
DETERMINE WEEK NUMBER FOR THE YEAR
IS THE WEEKLY TEMP. ≤ 28°
YES
SET ET & EVAP FOR TIME INCREMENT = ZERO
NO
ETCALC
EVAP
SUBSUR
INFIL
PEROUT
HAVE ALL ZONES BEEN CALCULATED
NO
INCREMENT ZONE INDEX
YES
CONVERT BREAKPOINT TIME VALUES TO ROUTING INTERVALS
ROUTE
PRINT STORM OUTPUT
YES
CALCULATE TIME, VOL, RATE AND CFS
PRINT OUTPUT INTERVAL
NO
INCREMENT ROUTE LOOP
HAVE ALL INTERVALS BEEN ROUTED
NO
YES
HAVE ALL DELTA TIMES BEEN CALCULATED
NO
INCREMENT TIME LOOP (J)
YES
HAVE 24 HOURS BEEN CALCULATED
NO
YES
OUTPUT
POLLUT
LAST DAY OF MO. BEEN CALCULATED
NO
END OF DATA ENCOUNTERED
YES
NO
SAVE MONTHLY SUMMARY
YES
LAST DAY YR. OR DATA ENCOUNTERED
NO
YES
SUMRY
YES
DONE
NO
INITIALIZE YEARLY VALUES
YES
STOP

Figure VI-2. Flow Diagram for the ARS USDAHL-75 Model (Ref. 9)

$$MELT = 0.15 * (T-THAW) * (1.0 - .5\ VEG) + (2P)$$

where: P = inches falling as rain that day
T = weekly average air temperature (^{o}F)
$THAW$ = temperature at which snowmelt starts (^{o}F)
VEG = weighted average of vegetative density
$MELT$ = potential snowmelt per day

c. Evapotranspiration. Evapotranspiration potential is estimated by the equation:

$$ET = GI \cdot K \cdot E_p \cdot \left[(S-SA)/AWC\right]^x$$

where: ET = evapotranspiration potential (in./day)
GI = crop growth index, relates temperature and tillage practices to crop growth
K = ratio of GI to pan evaporation
E_p = pan evaporation (in./day)
S = total porosity
SA = available porosity
AWC = porosity drainable only by ET
$x = AWC/G$ (G = gravity-free water)

Actual evapotranspiration is then computed by relating evapotranspiration potential to available soil moisture. Evapotranspiration increases with soil moisture to the point of field capacity, then it decreases because of the exclusion of oxygen from the soil under saturated conditions. Evaporation, however, will continue to increase with soil moisture until it equals pan evaporation at soil saturation. For this reason, the model calculates evaporation separate from evapotranspiration.

d. Infiltration. Infiltration is estimated by the equation:

$$f = (GI \cdot a \cdot S_a{}^{1.4}) + f_c$$

where: f = infiltration capacity (in./hr)
GI = crop growth index
a = index of surface-connected porosity (in./hr/in. of available storage)
S_a = available storage in surface layer
f_c = constant rate of inflow after prolonged wetting (in./hr)

Other factors used by the model to influence infiltration are V_d, the volume of water stored in depressions on the soil surface during rainfall before it is able to infiltrate, and percent soil cracking. Percent cracking is determined for the surface layers of the soil and is dependent upon the bulk density and the clay content of the soil.

e. Flow Routing. Each watershed is divided into hydrologic response zones by land capability classes. The zones correspond to the typical elevation sequences of uplands, hillsides, and bottomlands. Zone 1 would therefore be uplands, and the highest zone (usually 3) would be alluvium. The model uses the different zones to simulate the hydrologic processes involved when water cascades from one soil type to another during runoff.

The zones are further divided into groundwater flow regimes. These correspond to different soil layers, the most important being the A and B horizons. Input parameters m_n and q_n describe the groundwater outflow and storage capacity for each regime in each zone and can be derived either from post rainfall recession curves or empirically from soil survey data.

The simultaneous solution of a storage function and the continuity equation is used to route channel and subsurface return flows. The following adaptations of the continuity equation are used to compute overland flow:

$$\Delta D = Pe - Q_o$$

and $$q_o = (ova)D^n$$

where:

Pe = volume of excess precipitation per unit of time

Δ = increment

D = average depth of flow (in.)

Q_o = volume of outflow per unit of time

q_o = overland flow (in./hr)

n = 1.67 for turbulent flow

ova = coefficient estimated empirically from vegetative density, percent slope, and length of flow path.

For each flow regime, infiltrated water is proportioned to evapotranspiration or evaporation and to downward seepage or lateral return flow. Seepage from one regime is condisered inflow to the next regime. Separate values of maximum seepage rate, maximum free-water capacity and a storage coefficient are used to compute downward seepage for each regime in each zone.

f. Input and Output. Model output consists of daily, monthly, and yearly summaries of precipitation, runoff, groundwater recharge, evaporation-evapotranspiration, and return flows for each zone and the totals for the entire watershed. A description of input parameters is given in Table VI-2.

2. Description of the Agricultural Runoff Management Model

a. General. Written for an IBM 370/168 computer using FORTRAN IV language, the basic Agricultural Runoff Management (ARM) Model simulates hydrology, the pesticide and nutrient runoff processes, and the sedimentation processes. Modifications to the program were made and it was able to run on the Boeing Computer Service's CDC Cyber 175 computer. Eight of the 15 subroutines are used only for the pesticide, sedimentation, and nutrient simulations and were therefore removed. For a one-year run simulating hydrologic processes only, the program uses 9.4 CP seconds compilation time and 63.4 CP seconds execution time. The total job processing cost is approximately 664 CCUS.

The program was found to be sometimes difficult to follow. The subroutines are somewhat loosely organized. For example, program output is generated in the main program and subroutine LANDS, as well as in the two output subroutines OUTMON and OUTYR. Subroutine LANDS is quite large, and because all of the hydrologic processes are simulated in it, the output statements are difficult to separate from the remainder of the subroutine when modifications or changes are to be made. Comment statements are used, but they do not adequately describe the variables or computational steps. There is one input file and one output file. A description of each subroutine is in Table VI-3. A flow diagram of the hydrologic simulation portion of the model is shown in Figure VI-3.

b. Precipitation and Snowmelt. Precipitation data can be input in 5, 15, or 60-minute time intervals depending on the type of data available. The same time interval must

TABLE VI-2. REQUIRED INPUT DATA FOR ARS USDAHL-75 INPUT PARAMETERS

Parameter	Required Information
COMMENTS	Any information which might identify the run to the user.
DATES	Dates for storm hydrograph output in which detailed information is to be saved.
W/S	Watershed area (acres).
ZONES	Number of hydrologic response units.
ROUTING CO-EFFICIENTS	Total: total number of segments in recession curve at a downstream point in encompassing watershed or region. Above Weir: total number of segments in observed recession at the outlet of the watershed.
NUMBER OF CROPS	Number of crops of land use practices.
DEEP GROUND WATER RECHARGE	Deep percolation rate that does not show up on recession curve (in./hr)
DOES LAND USE CHANGE	Yes/no. Do any of the crop distributions or practices change within the simulation period?
DOES TILLAGE CHANGE	Yes/no. If tillage practice is available yearly for each crop and it changes, answer "yes".
Z NUMBER	Zone Number
% W/S	Percent areal distribution of zone on watershed.
LENGTH	Average length of flow on zone (ft).
% SLOPE	Average slope of zone.
F_c	Final rate of infiltration (in./hr).

TABLE VI-2. REQUIRED INPUT DATA FOR ARS USDAHL-75 INPUT PARAMETERS (Continued)

Parameter	Required Information
TOPSOIL	Depth of A horizon (in.)
TOTAL SOIL ZONE NUMBER	Depth of well drained, aerated soil (in.).
% G	Percent soil layer depth drained by gravity for each zone.
% WP	Wilting point of soil layer for each zone (% volume).
% FCAP	Percent soil layer drained by plants plus wilting point for each zone.
% TP	G + FCAP
% ASM	Percent soil layer depth holding water at beginning of simulation for each zone.
% CRACKING	Percent topsoil depth subject to cracking.
delta	Desired calculation period for channel routing (hr).
m_c	Channel routing coefficient.
INITIAL	Channel flow rate at beginning of simulation (in./hr).
INITIAL SNOW	Water equivalent of snow at beginning of simulation (in.).
THAW	Temperature at which snowmelt starts (^oF).
q_1 to q_4	Maximum rates of flow associated with each linear segment of the recession curve except the channel flow segment (in./hr).
m_1 to m_4	Routing coefficients of segments, not including channel (hr).
% SUBFLOW DIVERTED	Percent subsurface flow from upper zones that goes directly to the channel.

TABLE VI-2. REQUIRED INPUT DATA FOR ARS USDAHL-75 INPUT PARAMETERS (Continued)

Parameter	Required Information
% z_n CASCADING $z_n + 1$	Percent of overland flow from zone z_n that cascades over zone $z_n + 1$.
REMAINDER	Flow that does not cascade sequentially but goes directly to channel or alluvium but not both.
CROP NAME	Name of each crop or cultural practice.
A VALUES	Basal area of vegetation used as index of surface connected porosity.
Vd	Volume of depressions able to store rainfall until it infiltrates (in.).
ET/EP	Ratio of maximum evapotranspiration to maximum pan evaporation for a year.
ROOT DEPTH	(in.)
TU	Temperature above which crops evapotranspiration is impared (°F).
TL	Temperature below which crop evapotranspiration is impared (°F).
TEMPERATURES	Consecutive weekly average of daily mean temperature (°F).
GZ	Percent reduction in evapotranspiration attributable to grazing (yearly average)
TIL	Types of tillage practices.
MMDDYY	Date of tillage practice.
% CROP	Percent of zone in a particular crop.
EP	Consecutive weekly averages of pan evaporation (in./day).

TABLE VI-3. DESCRIPTION OF ARM MODEL SUBROUTINES

Subroutine	Description
MAIN	Reads in all input parameters and precipitation and climatological data. Main also calls all the subroutines.
CHECKR	Checks the input sequence for errors and prints out error messages.
CHECKS	Checks input parameters for errors.
BLOCK DATA	Initializes data for common variables.
OUTMON	Prints monthly output summaries.
OUTYR	Prints yearly output summaries.
LANDS	Simulates the processes of interception, infiltration, overland flow, percolation, evapotranspiration and snowmelt. It also accounts for all flow components. LANDS is a modification of the Stanford Watershed Model (Ref. 11) and Hydrocomp Simulation Programming (Ref. 12).

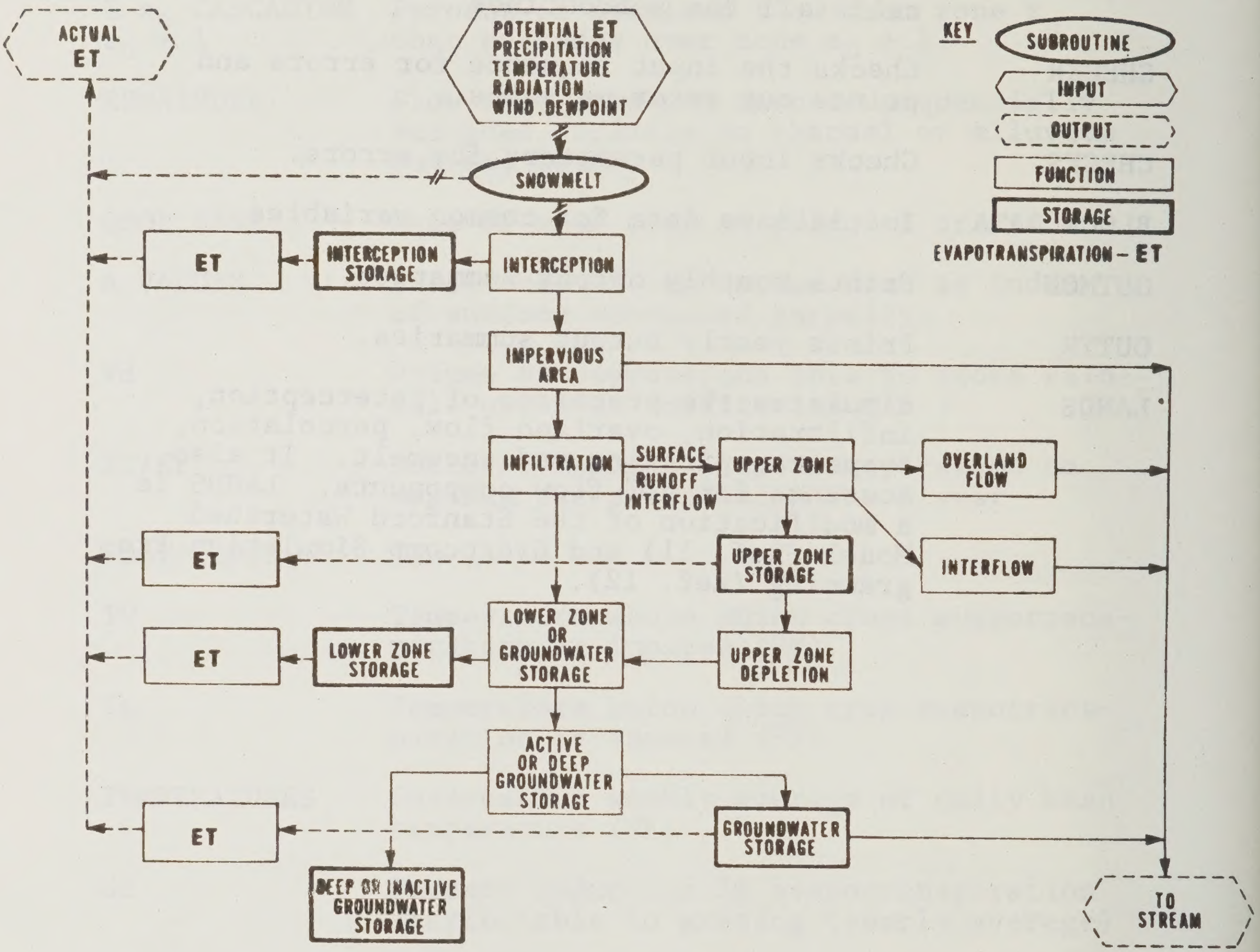

ACTUAL ET
POTENTIAL ET
PRECIPITATION
TEMPERATURE
RADIATION
WIND, DEWPOINT
KEY
SUBROUTINE
INPUT
OUTPUT
FUNCTION
STORAGE
EVAPOTRANSPIRATION - ET
SNOWMELT
ET
INTERCEPTION STORAGE
INTERCEPTION
IMPERVIOUS AREA
INFILTRATION
SURFACE RUNOFF INTERFLOW
UPPER ZONE
OVERLAND FLOW
ET
UPPER ZONE STORAGE
INTERFLOW
ET
LOWER ZONE STORAGE
LOWER ZONE OR GROUNDWATER STORAGE
UPPER ZONE DEPLETION
ACTIVE OR DEEP GROUNDWATER STORAGE
ET
GROUNDWATER STORAGE
DEEP OR INACTIVE GROUNDWATER STORAGE
TO STREAM

Figure VI-3. Flow Diagram of the Hydrologic Simulation Portion of the ARM Model (Ref. 10)

be used for all precipitation data. If one-hour time interval precipitation data is used, the model breaks it up into 15-minute intervals. The LANDS subroutine always operates on a 5 or 15-minute time interval, while the other subroutines operate hourly, daily, monthly, or yearly.

Snowmelt is simulated in the model with the use of an energy balance algorithm. Wind, solar radiation, wet bulb temperature, forest or crop density, and air temperature all influence snowmelt. Snowmelt is calculated at the same (5 or 15-minute) interval as is precipitation.

c. Evapotranspiration. Evapotranspiration is a function of pan evaporation, monthly crop cover, and upper and lower zone storage. Temperature is related to evapotranspiration with the parameters PETMIN and PETMAX. If the temperature falls below PETMAX the result is a 50% reduction in evapotranspiration, and if the temperature falls below PETMIN the result is a 100% reduction.

d. Infiltration and Runoff. Infiltration is simulated by assuming that the infiltration capacity varies over the segment. This variation is assumed to be linear. The slope of this relationship is dependent upon the ratio of lower zone storage to nominal lower zone storage. Interflow is calculated by a similar process.

Runoff, groundwater recharge, groundwater recession, interflow and infiltration algorithms are calculated for each time interval. A general understanding of these algorithms can be obtained from the description of the input parameters in Table VI-4.

e. Output. Model output can be produced each time interval (e.g., hour, day, or month) as specified by the user. It consists of summaries of overland flow, interflow, baseflow, groundwater recharge, precipitation, evapotranspiration, crop cover and soil moisture storages.

3. Model Selection

The ARS USDAHL-75 model was selected for use in the hydrologic simulation of the Powder River Basin. In

TABLE VI-4. ARM MODEL INPUT PARAMETERS

Parameter	Description
HYCAL	Specifies type of information desired: PROD = production run, CALB = calibration run.
INPUT	Input units (english or metric).
OUTPUT	Output units (english, metric or both).
PRINT	Specifies interval of printed output (hour, day, or month).
ICHECK	On or off subroutine ICHECK checks input parameter values to see if they are within acceptable limits.
DISK	Controls output written onto disk file: LSRO, RROS, and/or EROS.
IDEBUG	On or off subroutine IDEBUG checks values written onto disk.
CHAR	Controls type of output written to disk.
TITLE	Title for data set on disk.
DSNFLO	Data set number for LSRO file.
DSNERS	Data set number for EROS file.
DSNROS	Data set number for RROS file.
INTRVL	Time interval of operation (5, 15, or 60 min.).
HYMIN	Minimum flow for printed calibration output during a time interval.
AREA	Watershed area.
BGNDAY BGNMON BGNYR	Date simulation begins: day, month year

TABLE VI-4. ARM MODEL INPUT PARAMETERS (Continued)

Parameter	Description
ENDDAY ENDMON ENDYR	Date simulation ends: day, month, year.
UZSN	Nominal upper zone soil moisture storage.
UZS	Initial upper zone soil moisture storage.
LZSN	Nominal lower zone soil moisture storage.
LZS	Initial lower zone soil moisture storage.
L	Length of overland flow, approximates the length of travel to a stream channel.
SS	Average overland flow slope.
NN	Manning's n for overland flow.
A	The fraction of impervious watershed area.
EPXM	Interception storage parameter, a function of crop cover density.
PETMUL	Correction factor adjusting input potential evapotranspiration data to conditions on the watershed.
K3	Monthly index to actual evapotranspiration from lower soil moisture zone.
INFIL	Mean infiltration rate for the watershed.
INTER	Interflow parameter, alters runoff timing.
IRC	Interflow recession rate.
K24L	Fraction of groundwater recharge percolating to deep groundwater.
KK24	Groundwater recession rate.
K24EL	Fraction of watershed area where groundwater is within reach of vegetation.

TABLE VI-4. ARM MODEL INPUT PARAMETERS (Continued)

Parameter	Description
SGW	Initial groundwater storage.
GWS	Initial groundwater slope.
KV	Parameter to allow variable recession rate for groundwater discharge.
ICS	Initial interception storage.
OFS	Initial overland flow storage.
IFS	Initial interflow storage.
SNOWPRINT	Hourly snow tables printed? (yes or no)
RADCON	Correction factor for radiation melt, sensitive to watershed slopes and exposure.
CCFAC	Correction factor for condensation and convection melt.
SCF	Correction factor for raingage snow catch deficiency.
ELDIF	Elevation difference from temperature station to mean watershed elevation.
IDNS	Initial density of new snow @ 0^{o}F.
F	Fraction of watershed with complete forest cover.
DGM	Daily groundmelt.
WC	Water content of snowpack by weight.
MPACK	A function of topography and climate which estimates water equivalent of snowpack for complete areal coverage.
EVAPSN	Correction factor for snow evaporation.
MELEV	Mean watershed elevation.

TABLE VI-4. ARM MODEL INPUT PARAMETERS (Continued)

Parameter	Description
TSNOW	Temperature below which precipitation becomes snow.
PACK	Initial water equivalent of snowpack.
DEPTH	Initial depth of snowpack.
PETMIN	Below this temperature evapotranspiration is zero.
TETMAX	Below this temperature evapotranspiration is reduced by 50%.
WMUL	Correction factor for input wind data.
RMUL	Correction factor for input radiation data.
KUGI	Index to forest density and undergrowth.

similar test runs, the ARS model used 501 job processing CCUS less than the ARM model. This was the primary reason for its selection. The time increments for which calculations are performed as well as the fact that the ARS model is designed solely for hydrologic simulation while the ARM model must make considerations for pesticide, nutrient and sediment simulation are the primary reasons for the differences in computer cost.

With proper calibration, the accuracy of both models would be sufficient for surface water modeling in the Powder River Basin. It should be noted that the accuracy of the ARS model can be enhanced by a better representation of snowmelt. Perhaps the use of the snowmelt algorithm in the ARM model could be included in the ARS model.

The ARS model is clearly more adaptable and easy to use. The clear divisions between subroutines and the extensive use of comments will make it easy for future users to understand. In addition, the five output files will aid in its incorporation with the other components of the total hydrologic simulation model of the Powder River Basin.

D. Data Collection

The computer model schematic shown in Figure VI-1 requires a variety of input data. Before a watershed for model calibration and verification is chosen, one must be aware of the data requirements of the models. The following types of input data are needed.

- Precipitation - Hydrologic simulation models such as the Stanford Watershed Model and ARS Hydrologic Model require hourly precipitation data input. Daily rainfall accumulations within the watershed are also useful. The greatest source of error in the use of hydrologic simulation models is inaccurate rainfall data. Daily rainfall accumulations can be used to adjust hourly records to find an accurate, watershed-wide precipitation. Thus, the watershed chosen for model calibration and verification should have a number of precipitation stations, both hourly and daily.

- Other Meterologic Data - A number of other types of meterologic data are necessary. The most important of these is daily pan evaporation. Pan evaporation data are used to calculate evapotranspiration in the hydrologic simulation model. Other meterologic data are required if snowmelt is to be computed, which it will be in the Powder River Basin. Data required for snowmelt computations are daily maximum and minimum temperature, daily wind movement, daily solar radiation, and daily dew point temperatures. The models are not as sensitive to this data as they are to precipitation, so it is not necessary to have a weather station in the watershed to measure these parameters. The data can be obtained from the nearest first class weather station.

- Watershed Characteristics - A variety of data about the watershed being simulated is required. Watershed area, slope, and length of overland flow are obtained from USGS topographic maps. Soil characteristics such as field capacity, wilting point, and infiltration rate will be estimated from U.S. Soil Conservation Service soil surveys. Other necessary parameters are estimated and used to calibrate the models.

- Channel Characteristics - Channel characteristics are required for the streamflow routing subroutines. Channel width, slope and Manning's n are required parameters. Channel slopes can be measured from USGS topographic maps. Channel widths can be estimated for alluvial valley streams using the relationships of hydromorphology (Ref. 13). Manning's n for each channel reach will be estimated after field inspection.

- Aquifer Characteristics - The groundwater flow model will be used to simulate the hydrology of the shallow aquifers in the watershed. Aquifer characteristics, boundary data, and recharge are required input data. Boundary data will be obtained from the output of the regional model. Recharge values will be obtained from the hydrologic simulation model. Aquifer characteristics, such as transmissivity, will be obtained from geological data and pumping tests.

- Stream Flow Data - The single most important selection criterion for a watershed in which to calibrate and verify the system of models is the presence of a USGS stream gaging station. The daily watershed surface outflows must be used for the calibration and verification of this system of models.

The Sarpy Creek watershed in southeastern Montana and the northern part of the Powder River Basin has been chosen as the initial test watershed. There are a number of reasons for this selection. There is a USGS stream gaging station for the watershed. Precipitation data is available at two U.S. Weather Service daily gages, one in the watershed, the other just outside the watershed. Meterological data, including pan evaporation and hourly rainfall, is collected by Westmoreland Resources at their Sarpy Creek surface coal mine, which is in the southern part of the watershed. Hittman Associates presently has 31 wells in the watershed at which monthly monitoring data is collected. Twenty-eight of these are Westmoreland Resources monitoring wells. Other miscellaneous data is available for the Westmoreland mine area in the Environmental Impact Statement for the mine (Ref. 14). The Sarpy Creek watershed and the locations of these data stations are shown in Figure VI-4.

The data listed above and shown in Figure VI-4 will be augmented with the addition of a continuous recording rain gage. The siting of this gage is yet to be decided. A Belfort Universal Recording Rain Gage with 12-inch dual traverse has been ordered. The rain gage will be equipped with an electric clock and 7-day charts. An Alter wind shield and/or a snow fence will be installed with the rain gage.

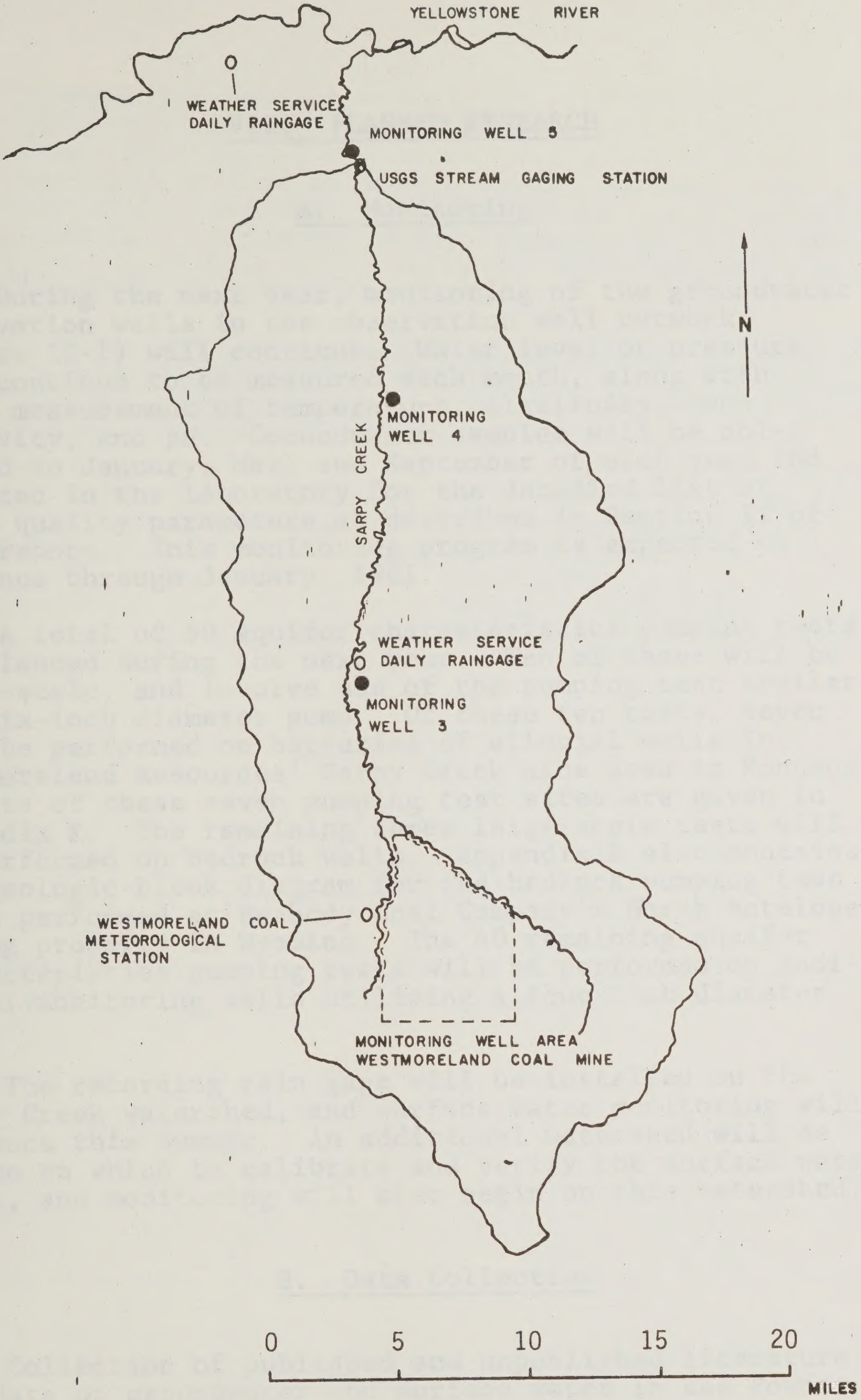

YELLOWSTONE RIVER
WEATHER SERVICE DAILY RAINGAGE
MONITORING WELL 5
USGS STREAM GAGING STATION
N
MONITORING WELL 4
SARPY CREEK
WEATHER SERVICE DAILY RAINGAGE
MONITORING WELL 3
WESTMORELAND COAL METEOROLOGICAL STATION
MONITORING WELL AREA WESTMORELAND COAL MINE
0
5
10
15
20
MILES

Figure VI-4. First Watershed Selected for Surface Water Model Calibration and Verification

VII. PLANNED RESEARCH

A. Monitoring

During the next year, monitoring of the groundwater observation wells in the observation well network (Figure II-1) will continue. Water level or pressure will continue to be measured each month, along with field measurement of temperature, alkalinity, conductivity, and pH. Groundwater samples will be collected in January, May, and September of each year and analyzed in the laboratory for the detailed list of water quality parameters as described in Section II of this report. This monitoring program is expected to continue through January, 1981.

A total of 50 aquifer characteristics pumping tests are planned during the next year. Ten of these will be large-scale, and involve use of the pumping test trailer and six-inch diameter pump. Of these ten tests, seven will be performed on batteries of alluvial wells in Westmoreland Resources' Sarpy Creek mine area in Montana. Layouts of these seven pumping test sites are given in Appendix K. The remaining three large-scale tests will be performed on bedrock wells. Appendix K also contains the geologic block diagram for the bedrock pumping test to be performed at Peabody Coal Company's North Antelope mining property in Wyoming. The 40 remaining aquifer characteristics pumping tests will be performed on individual monitoring wells utilizing a four-inch diameter pump.

The recording rain gage will be installed on the Sarpy Creek watershed, and surface water monitoring will commence this summer. An additional watershed will be chosen on which to calibrate and verify the surface water model, and monitoring will also begin on this watershed.

B. Data Collection

Collection of published and unpublished literature and data on groundwater and surface water in the Powder River Basin will continue. The latest U.S. Weather

Service and USGS data required for model development and calibration will be obtained. Airphotos showing the extent of phreatophytes in the Powder River Basin have been ordered. These airphotos will be utilized to further quantify the amount of evapotranspiration in the basin. This data collection effort will continue throughout the course of the project.

C. Modeling

Refinement of the groundwater model, which is already on-line, will continue as additional data becomes available. The selected surface water model will continue to be modified and tested to make it compatible with the groundwater model. Work will also continue on the subroutines to link the ground and surface water models and obtain the overall hydrologic simulation model diagrammed in Figure VI-1.

VIII. REFERENCES

1. Hittman Associates, Inc., Monitoring and Modeling of Shallow Groundwater in the Powder River Basin - Phase I Report, HIT-682, U.S. Bureau of Mines Contract No. J0265050, January 1977, 83 pp.

2. Hittman Associates, Inc., Monitoring and Modeling of Shallow Groundwater in the Powder River Basin - Annual Technical Report, HIT-721, U.S. Bureau of Mines Contract No. J0265050, February 1978, 94 pp.

3. Sokoloff, V.P., "Water of Crystallization in Total Solids of Water Analysis", Industrial and Engineering Chemistry, December 15, 1933, pp. 336-337.

4. Prickett, T.A. and C.G. Lonnquist, Selected Digital Computer Techniques for Groundwater Resource Evaluation, Bulletin 55, Illinois State Water Survey, Urbana, 1971, 62 pp.

5. Robinson, T.W., Phreatophytes, U.S.G.S. Water Supply Paper No. 1423, 1958, 84 pp.

6. Hughes, G.H. and C.C. McDonald, "Determination of Water Use by Phreatophytes and Hydrophytes", American Society of Civil Engineers, Journal of Hydraulics Division, Vol. 92, No. HY2, March 1966, pp. 63-81.

7. Horton, J.S., T.W. Robinson, and R. McDonald, Guide for Surveying Phreatophyte Vegetation, USDA, Forest Service, Agriculture Handbook 266, 1964, 37 pp.

8. Kirkham, P. and S.B. Affleck, "Solute Travel Times to Wells", Groundwater, Vol. 15, No. 3, May-June 1977, pp. 231-242.

9. Holtan, H.N., G.J. Stiltner, W.H. Henson, and N.C. Lopez, USDAHL-74 Revised Model of Watershed Hydrology, Technical Bulletin No. 1518, U.S. Department of Agriculture, Agricultural Research Service, December 1975, 99 pp.

10. Donigian, Anthony S., Jr. and H.H. Davis, Jr., User's Manual for Agricultural Runoff Management (ARM) Model, U.S. Environmental Protection Agency, Report No. EPA-600/3-78-080, August 1978, 163 pp.

11. Crawford, N.H. and R.K. Linsley, Digital Simulation in Hydrology: Stanford Watershed Model IV, Technical Report No. 39, Department of Civil Engineering, Stanford University, Stanford, California, 1966, 210 pp.

12. Hydrocomp, Inc., Hydrocomp Simulation Programming Operations Manual, 4th Edition, 1976, 115 pp.

13. Osterkamp, W.R. and E.R. Hedman, "Variation of Width and Discharge for Natural High-Gradient Stream Channels", Water Resources Research, Vol. 13, No. 2, 1977, pp. 256-258.

14. U.S. Geological Survey, Final Environmental Statement - Proposed 20-Year Plan of Mining and Reclamation, Westmoreland Resources Tract III, Crow Indian Ceded Area, Montana, November 9, 1976, 495 pp.

APPENDIX A

GROUNDWATER
MONITORING PROCEDURES
AND EQUIPMENT
MAINTENANCE

August 1978

Hittman Associates, Inc.
Englewood, Colorado 80111
Billings, Montana 59107

I. Water-Level Measuring

A. Purpose

The purpose of the water level measuring program is to measure the static water level of the shallow groundwater in the Powder River Basin at as many points as possible on a monthly basis. We are interested in water levels in wells that are less than 500 feet deep. The static water level is one which is not effected by pumping. Thus, a well with no pump is the best kind of well to measure. Next best is a well where the pump is turned off, but even a measurement in a pumped well gives us some indication of the static water level.

B. Procedure

If the well is not being pumped, lower the M-scope probe down the hole until the water level is indicated by a deflection to the right by the amp meter needle. If the well is a windmill, care must be taken to insure that the reading is taken at the static water level and not at the drain hole located between 15 and 30 feet below the ground level. If it is suspected that these drain holes are interfering with the operation of the M-scope and that a true reading cannot be obtained with it, use a 100 foot steel tape and special popper to measure static water level. When using the M-scope, do not let the probe free-fall into the water. After the initial static water level reading is made, raise the probe until the meter needle deflects back towards 0. Slowly lower the probe until the needle again deflects to the right indicating that the probe is in contact with the water. Measure from the nearest five foot marker on the cable to the point on the cable that is at the painted measuring point on the well casing. This measurement should be to the nearest tenth of a foot. Subtract or add this measurement (depending on the location of the five foot marker relative to the point on the cable) to the number at the five foot marker to get the water level depth from the casing. Subtract or add the well constant to this water level depth to convert the reading to depth below the ground surface (Figure I). If the tape and special popper are used, be sure to add the popper constant to the reading on the tape. Record the total depth to water in feet and tenths of feet.

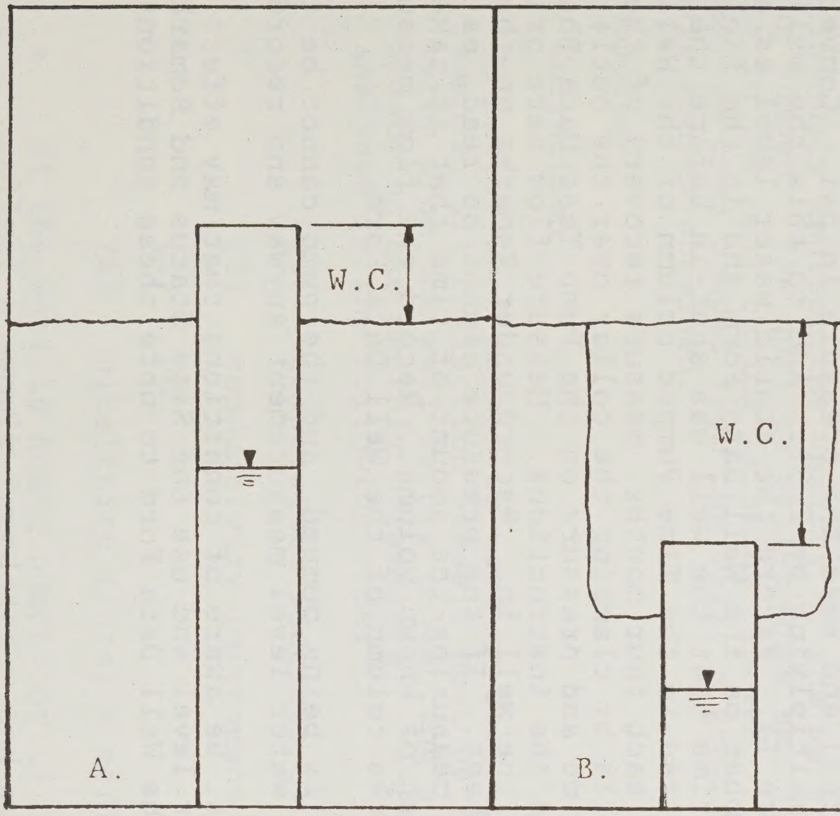


Figure A-1. Various well constants (W.C
the water level reading. A)
level - subtract W.C.; B)
W.C.; C) Artesian (flowing)

If the well is being pumped, take the water sample first (see water quality sampling protocol). Turn the pump off, wait 15-20 minutes and measure water level. Record the water level and time since pump shut-down in the Water Level and Time Pumped columns respectively of the field book and Well Data Form. At least once every four months, perform a recovery test by continuing to make water level measurements at intervals specified on the water level measuring schedule until 30 minutes have elapsed or until the change in water level is less than 0.5 feet. Measure flow rate before turning the pump off. Record the flow rate under Remarks on the Pump Test Data Sheet. Record all water levels and times on the Pump Test Data Sheet according to the Instructions for Filling Out the Pump Test Data Sheet. Record times in minutes and water levels in feet and tenths of feet. Record the final water level reading in the Water Level column of the field book and Well Data Form.

If the well is a flowing well, take the water sample first (see water quality sampling protocol), then clamp the appropriate size artesian collar over the end of the discharge pipe. Hold the gauge at the measuring point marked on the discharge pipe. Wait until the pressure stabilizes (15-20 minutes) and read the pressure in psi. Convert psi to feet by multiplying by 2.31. Add to this the well constant (Figure I). Record the static water level as a negative number on the Well Data Form and in the field book. Record the time that the well was shut-in before the pressure stabilized in the Time Pumped column of the Well Data Form. Once each four months, measure recovery of the artesian wells by clamping the collar over the outlet and recording time and pressure on the Pump Test Data Sheet according to the instructions. Measure flow rate prior to shutting the well in. Record under Remarks on the Pump Test Data Sheet. If the pressure cannot be read, estimate the flow by measuring the amount of time that it takes to fill a bucket of known volume. Record the flow measurement in the Remarks column of the Well Data Form.

If the well is being pumped, and the pump cannot be turned off, make a water level measurement anyway and record it.

At all times, be aware of conditions that may effect the static water level and use the Site Status and Remarks fields on the Well Data Form to note these conditions.

I. Monthly Water Quality Sampling

A. Purpose

The purpose of the monthly water quality sampling program is to measure the pH, conductivity, temperature and alkalinity of the groundwater in the Powder River Basin at as many points as possible on a monthly basis. We are interested in wells that are less than 500 feet deep. The ideal water sample is one that is not contaminated by well packing, well casing, or other piping. Thus, the best water sample is one from a continuously flowing or pumped well, where the water spends the shortest possible time in contact with the well casing. A good water sample can also be obtained by pumping water from an unpumped well. The volume of water pumped should be greater than the volume of water lying stagnant in the bottom of the well casing. After this volume of water has been pumped, or otherwise removed from the well, then the water sample can be taken. One way of estimating the volume of water that must be pumped from the well before a good water quality sample can be obtained, is to continuously monitor the quality of the water as it is being pumped. The quality will change as the stagnant water in the well casing is being removed. Once all this water has been pumped from the well, a good water quality sample can be obtained.

B. Methodology

1. Collection

No matter what method is used to collect the water sample, all collection vessels must be rinsed with water from the well before collecting a sample for measuring the monthly parameters. Perform the analyses in the following order:

(1) temperature (degrees C)

(2) conductivity (micromhos/meter)

(3) pH

(4) alkalinity (total - mg/l of $CaCO_3$)

a. If the well is being pumped or is flowing, collect a sample immediately and measure the parameters. Turn off the pump and measure static water level (see Water Level Measuring).

HITMAN

b. If the well is not being pumped but has a pump, record the water level first (see Water Level Measuring), then turn the pump on for at least 15 minutes before collecting a sample for measuring the monthly parameters. Record the time pumped in the Time Pumped field on the Well Data Form.

c. If the well has no pump, record the water level (see Water Level Measuring). If the well is one designated to be pumped on the monthly monitoring program, lower the pump to at least 30 feet below static water level. Pump the well for approximately 15 minutes with the discharge valve fully open. At the end of the 15 minutes, collect a sample and measure the four monthly quality parameters. Record the time pumped on the Well Data Form.

d. If the well has no pump and is not to be pumped, use the sampler to obtain a sample. Fill the sampler once with water from the well. Use this water to rinse the collection vessel. Pour the rest of the water out. Collect another sample with the sampler. This sample must be taken from at least 10 feet below the static water level in the well. Pour the water into the collection vessel and measure the four monthly parameters.

2. Quality Control

If pH, temperature, or alkalinity readings are over 25% different from those obtained on the previous month's sampling run, collect a new sample and repeat all four tests. If conductivity is over 50% different from the previous run, collect a new sample and repeat all four tests. If the tests are repeated, record the results of the first set of tests in the Remarks column and the second set of results in the appropriate areas of the Well Data Form.

3. Temperature and Conductivity Analysis

a. Check that the meter reads zero. If out of adjustment, turn the bakelite screw on the meter face so that the meter needle coincides with the zero on the conductivity scale.

b. Remove probe from meter at probe jack.

c. Check the calibration of the meter by turning the switch to redline and adjusting the meter needle with the redline control to the redline on the scale. If this cannot be accomplished, replace the batteries.

d. Plug the probe into the probe jack on the side of the meter.

Note:

The above steps should be done each time that the meter is used.

e. Rinse the probe with distilled water.

f. Insert the probe in the solution to be measured.

g. Set the switch to temperature. Read the temperature in degrees Celsius. Allow time for the probe temperature to come to equilibrium with that of the water before reading.

h. Switch the meter to the X100 micromhos/cm range. If the reading is below 50 on the 0-500 scale, switch to the next lower range (X10 micromhos/cm). If the reading is still below 50, switch to the next lower range (X1 micromhos/cm). Read the meter scale and multiply that reading by the range selected.

i. When measuring the X100 and X10 ranges, depress the CELL TEST button. If the meter reading should fall greater than 2%, the probe is fouled and the measurement is in error. The CELL TEST button does not function on the X1 range (see Probe Cleaning and Meter Calibration under Maintenance).

j. Remove the probe from the solution and rinse with distilled water.

4. pH Analysis

a. Set the TEMPERATURE adjustment on the pH meter to the approximate temperature of the buffer solutions.

b. Remove the glass cap from the tip of the probe. Do not lose this cap.

c. Rinse the probe with distilled water twice.

d. Insert the probe in the pH 7 buffer solution and calibrate the meter using the CALIBRATION knob. Rinse the probe with distilled water.

e. Insert the probe in a different buffer solution of pH 10 or pH 4 and check the calibration. If the meter does not read correctly, bring the meter to the correct value for the solution by using the TEMPERATURE knob. DO NOT use the CALIBRATION knob for this part of the calibration. If unable to calibrate, the meter may need repair, the probe may have gone bad, or the batteries are low.

f. Rinse the probe with distilled water.

g. Insert the probe in the water sample while swirling or stirring the sample. Turn the meter on. Record the reading of the digital display. The read-out may change slowly due to sodium ion interferance. Record the initial value of pH.

h. Rinse the probe with distilled water. Replace the glass cap on the end of the probe. Keep the end of the probe wet at all times.

i. If the pH meter is inoperative, use the pH test paper kits.

  (1) First determine the approximate pH of the sample by using the wide range paper and comparing the changed color on the test strip with the chart on the front of the box.

  (2) Using the correct narrow range paper, determine the pH to two-tenths of a pH unit. This is done using the same color comparison technique as used in step i.(1).

Remember -

Be careful of the probe. The tip of the probe is a very thin, fragile glass membrane. When not in use, the tip of the probe is to be kept wet with distilled water or pH 4 buffer at all times. Never allow the tip of the probe to dry out as this will ruin it. When ambient air temperature is below approximately 40°F (4.5°C) take the pH reading with the meter, probe and water sample in the cab of the truck. This is to prevent possible breakage of the probe due to freezing of the KCl-AgCl solution. At no time expose the probe to a temperature below 32°F (0°C). The probe is always to be stored in an area where the temperature is above 40°F. Keep refillable probes filled with saturated CKl-AgCl solution. (Fill up to, not over the filling hole). Keep the rubber band over the filling hole when using the probe.

5. Alkalinity Analysis

   a. Rinse the dipper and reaction vessel with the water to be sampled.

   b. Fill the 5 ml dipper to overflowing with the sample.

   c. Transfer the contents of the 5 ml dipper to the reaction vessel.

   d. Add three drops of the Bromcresol Green-Methyl Red Indicator to the reaction vessel and swirl to mix.

   e. Add sulfuric acid (0.02N) with the micro-burette assembly until the solution changes to blue-gray or pink. Swirl the reaction vessel while adding the acid.

   f. Multiply the number of drops of acid needed by 10 to obtain the total mg $CaCO_3$/l alkalinity.

   g. Rinse the dipper and reaction vessel with distilled water.

III. Monthly Maintenance of Test Equipment

A. Sampler

1. Keep the well water sampler clean to avoid contamination.

2. Check valve and attachment cord periodically for any malfunctions.

B. YSI Model S-C-T Meter

1. Probe Cleaning

When the CELL TEST indicates low readings, the probe needs to be cleaned. Clean by spraying DOW "Bathroom Cleaner", or Lysol "Basin, Tub, Tile Cleaner" on the inside of the probe. Let wait 5 minutes and rinse with distilled water. Repeat the cleaning. Check the probe and meter in the standard KCl solution. Depress the CELL TEST button while the probe is in this solution, the meter reading should drop less than 2%. If the meter is still in error, read the instruction book and confer with the Denver office. Cleaning should be done every month as well as when indicated by cell test reading.

2. Meter Calibration

Every month the calibration of the conductivity meter should be checked. A .01 Molar KCl solution should have a conductivity between 1350 micromhos/cm and 1485 micromhos/cm @ 25°C. At 20°C, the conductivity should be between 1205 micromhos/cm and 1340 micromhos/cm. These ranges are due to the inherent measurement error of the meter and the probe. If these standards cannot be met, the meter may be in need of repair. Confer with Denver before repair.

C. pH Meter

1. Check all probes to see that the ends are immersed in distilled water or pH 4 buffer at all times when not in use. THIS IS IMPORTANT.

2. Do not store probes in a cold place (less than 40°F (5°C)) where they will freeze. Take care of the probes; they are very fragile.

D. Alkalinity Test Kit

Each month wash the dipper and reaction vessel with soap and water. Rinse with tap water. Rinse with distilled water. Rinse again with distilled water. Let dry on a clean paper towel before replacing in kit.

E. Distilled Water Bottle

Before each sampling run, make sure you have a wash bottle filled with distilled water only. Distilled water can be bought at the supermarket in the laundry section.

F. Always carry spare alkaline batteries for the M-scope, pH meter, and S-C-T meter. Eight spare alkaline AA batteries and two spare size D alkaline batteries are needed.

G. Sampling Pump

1. AT NO TIME RUN THE PUMP UNLESS IT IS COMPLETELY IMMERSED IN WATER.

2. Always transport the pump in its wooden box to prevent damage.

3. Never allow the rubber hose to be exposed to direct sunlight for more than a few days at a time.

4. Maintain the generator as per manufacturer's instructions. Remember to change oil on the recommended schedule.

5. Once each month, check all electrical connections particularly those where the pump pigtail is attached to the electric cable. Retape connections as necessary. Also check all hose connections and wire rope sling once each month.

6. When lowering the pump down a well, do not let the hose or electric cable rub on the casing. Any nicks or cuts in the cable should be taped with waterproof electricians tape.

7. If any problems develop with the sampling pump, contact the Denver office about repairs.

HITTMAN

IV. Water Sample Collection for Lab Analysis

A. Every four months water samples are to be collected and sent back to the lab in Columbia. One large bottle (half gallon) and one small bottle (pint) are to be collected at each well. The small bottle is to be preserved by adding concentrated nitric acid (HNO_3) until the pH of the sample is just less than 2. Check the pH with the pH meter.

B. If the sampler is to be used to collect the water sample, it must be rinsed with well water at least once before the sample bottles are rinsed. If the well has a pump or is to be pumped with the sampling pump, run the pump for at least 15-20 minutes prior to collecting sample. Note time pumped on the Well Data Form.

C. When taking samples, rinse the bottles with water from the well prior to filling them. Place the bottles in the cooler of ice shortly after they have been collected. Collect a new sample and measure the monthly quality parameters.

D. Before shipping cooler to Columbia, repack it with fresh ice. Log all bottles on the Logging Form just before they are shipped.

E. In order to provide quality control samples for a check on the laboratory, duplicate samples (1 large bottle and 1 small bottle) will be collected, preserved as necessary, and shipped with the regular samples. Once each sampling run at least two wells will have these duplicate samples taken. The wells to be sampled, the sample numbers, and the dates to be assigned the duplicate samples will be selected by the task leader. Care must be taken on the duplicate acidified samples from a given well to ensure that the same amount of nitric acid is added to each small bottle.

Example:

Well number 48 is designated as a duplicate sample well. After samples have been collected in the bottles, it is found that 22 drops of concentrated nitric acid is needed to lower the pH of one small bottle to 2. Therefore, 22 drops of acid are to be added to one small bottle of the duplicate sample. The duplicate samples are then labeled with the number and date designated by the task leader.

F. Occasionally duplicate samples will be taken from a well and the duplicate sample will be shipped to Denver for analysis in another lab. In this case the duplicate sample will be numbered and dated the same as the original sample. Acidification of the small bottles is to be the same as described under IV-E.

APPENDIX B - MONTHLY MONITORING DATA

Contained herein are the data collected from the monthly groundwater monitoring program through October, 1978. The site status codes shown on the following pages are as given below.

Site Status Code	Meaning
D	The site was dry (no water in well). (A 99.9 will appear in field 3).
G	A nearby well was artesian (flowing) when the measurement was made.
H	A nearby well was not artesian (flowing) when the measurement was made but there is reason to believe it was recently flowing.
O	(Ø, not zero)-An obstruction was encountered in the well above the water level. A water level was not recorded and a 99.9 will appear in field 3 (Water level).
P	The well was being pumped. Turn the pump off and take a water level reading every five minutes for 30 minutes (6 readings) or until the water level changes less than .5 ft in a five minute interval. Record these readings on Well Data Form No. 2. Put the final reading in field 3 (Water level) on Well Data Form. This code has precedence over codes G, H, S, and T.
R	The well was not being pumped when visited but there is reason to believe the well had been recently pumped.
B	The well was being pumped. The pump could not be turned off and a water level measurement was made anyway.
S	A nearby well was being pumped.
T	A nearby well was not being pumped, but there is reason to believe that the nearby well had been pumped recently.

Site Status Code	Meaning
Z	Other conditions affecting the measured water level (explain in Remarks).
A	Non-artesian well with no pump, or well with pump off; no pumping or other conditions causing the water level of this well to be different from the true static water level.
F	Artesian (flowing) well.

Note: All 9's in any field indicates that the particular parameter was not measured on that date.

MONTHLY MONITORING DATA-POWDER RIVER BASIN

REPORT DATE - 78/12/18.

WELL NO.	DATE MM/DD/YY	FLOWING SIGN(-)	WATER LEVEL-FT	PH	TEMP DEG-C	ALKALINT MG/L	CONDUCT MM/CM	SITE STATUS	TIME PUMPED	REMARKS
1	10/10/77		37.9	99.9	10.0	220	497			
	11/15/77		38.2	8.2	11.5	280	463			
	12/19/77		38.9	8.1	10.0	260	539			
	01/23/78		39.0	9.3	8.0	240	426	A		FROZEN
	02/20/78		39.3	8.1	9.0	380	437	A		BROKEN WINDMILL, BOTTLE
	03/18/78		39.4	99.9	10.0	320	923	A		CLOUDY MUDDY APPEARANCE
	04/09/78		37.2	7.8	11.0	240	1036	A		BAILED SAMPLE
	05/08/78		35.9	8.5	13.0	220	978	A		THIEF SAMPLE
	06/05/78		31.8	8.3	12.0	200	667	A		
	07/17/78		28.3	8.3	14.0	216	647	A	0	BAILED SAMPLE
	08/16/78		28.5	8.3	11.5	221	586	A		BAILED
	09/15/78		29.4	8.4	10.3	230	641	A		THIEF SAMPLE
	10/27/78		29.5	8.6	10.9	210	762	A		CREEK FLOWING-BAILED
REC COUNT - 13 FOR 1										
10	09/20/77		35.1	7.5	16.0	880	2239			
	10/10/77		30.3	7.6	11.0	400	1658			
	11/16/77		26.7	7.4	10.5	420	2662			
	12/19/77		27.4	7.5	9.0	580	1735			
	01/23/78		999.9	99.9	99.9	9999	999999	Z		WELL FROZEN
	02/22/78		21.5	99.9	.0	9999	999999	Z		HOLDING TANK WELL FROZEN
	03/23/78		19.9	99.9	99.9	9999	999999	A		WELL FROZEN,
	04/12/78		19.4	7.2	8.0	440	3069	A		PH WITH PAPER
	05/09/78		19.4	7.6	12.0	580	2687	A		
	06/06/78		18.0	99.9	99.9	9999	999999	Z		FLOODED-PUMP OFF
	07/17/78		25.5	99.9	99.9	9999	999999	Z	0	PUMP INOPERABLE
	08/17/78		23.4	99.9	99.9	9999	999999	A		PUMP SHUT OFF ALL SUMMER
	09/30/78		21.6	99.9	99.9	9999	999999	A		PUMP NOT CONNECTED
	10/30/78		21.5	99.9	99.9	9999	999999	A		PUMP STILL OFF
REC COUNT - 14 FOR 10										
105A	09/20/78		159.9	7.4	10.5	590	1275	A		BAILED
	10/12/78		164.0	7.4	10.0	564	1249	A		BAILED
REC COUNT - 2 FOR 105A										
105B	09/20/78		167.1	7.4	11.5	560	1635	A		BAILED
	10/12/78		167.4	7.7	11.0	562	1658	A		BAILED
REC COUNT - 2 FOR 105B										
105C	09/20/78		148.4	7.9	13.0	450	1122	A		BAILED
	10/12/78		143.6	7.4	10.0	522	1264	A		BAILED
REC COUNT - 2 FOR 105C										
11	09/21/77		999.9	7.3	11.5	60	1090	Z		SPRING
	10/11/77		999.9	8.3	10.0	80	1491	Z		SPRING
	11/16/77		999.9	8.2	9.5	100	1439	Z		SPRING

```
                                                                                                   REPORT DATE -  78/12/18.
  WELL NO.     DATE        FLOWING   WATER       PH    TEMP     ALKALINT    CONDUCT   SITE     TIME                REMARKS
               MM/DD/YY    SIGN(-)   LEVEL-FT          DEG-C    MG/L        MM/CM     STATUS   PUMPED

 11            12/20/77              999.9       8.2    7.0       100         921      Z                  SPRING
               01/25/78              999.9       8.2    6.0        80         684      Z                  SPRING, CONTINUOUS
               02/22/78              999.9      99.9    7.0        80         767      Z                  CAN'T GET A PRESSURE TO BUI
               03/23/78              999.9       6.4    5.9        80        1609      Z                  SPRING, POSSIBLE SNOWMELT M
               04/12/78              999.9       6.3    8.5        80        1478      Z                  SPRING,PH WITH PAPER
               05/10/78              999.9       8.2    9.0       100        1276      Z                  SPRING
               06/07/78              999.9       7.9    9.0       153        1604      Z
               07/18/78        -       1.3       7.2   13.5       158        1471      Z                  SPRING
               08/18/78              999.9       7.7   10.0       146        1562      Z                  SPRING
               09/16/78              999.9       7.9    6.0       150        1652      Z                  SPRING
               10/07/78        -       1.1       8.0    9.1       130        1484      Z                  SPRING
       RFC COUNT -  14 FOR 11

 12            09/21/77               29.5       7.2   14.0       960        1877
               10/11/77               46.0       7.4   11.0       600        2625
               11/16/77               38.7       7.3   12.0       600        2552
               12/20/77               38.8       7.4    7.5       800        1592
               01/23/78               39.3       7.3    8.0       560        1272      A        2
               02/22/78               39.1      99.9   10.9       520        1607      P       13
               03/23/78               39.6       6.8   10.9       680        2743      P                  PH BY PAPER.
               04/27/78               39.8      99.9   11.3       720        2775      A        2
               05/10/78               39.2       7.3   13.0       720        2349      A        2
               06/07/78               39.3       7.3   11.0       798        2763      A        2
               07/18/78               38.8       7.2   14.0       891        2687      A       02
               08/17/78               38.8       6.9   11.5       891        2827      A       15
               09/16/78               38.3       7.2    8.8      1000        2925      A
               10/07/78               38.5       7.5   10.5       864        2676      A       16
       REC COUNT -  14 FOR 12

 13            09/21/77               68.5       8.3   15.0       740        2031
               10/11/77               65.8       8.5   10.0       520        2556
               11/16/77               65.1       8.4   11.0       640        2073
               12/20/77               63.3       8.3    9.0       620        1750
               01/25/78               73.1       8.6    8.5       540        1551      A        3
               02/22/78               64.7      99.9   11.0       540        1934      P       15        HOLDING TANK
               03/23/78               65.6       7.2   10.1       580        2677      R       20        PH BY PAPER. HOUSE PRESSURE
               04/27/78               63.5      99.9   10.8       600        2793      R       15
               05/10/78               63.1       8.2   13.0       680        2447      R       15
               06/07/78               65.2       8.1   12.0       732        2821      B        5        PUMP RUNNING.
               07/18/78               65.8       8.1   16.0       863        2737      R       05        DOMESTIC SUPPLY
               08/18/78               65.4       8.2   12.5       862        2681      R       15
               09/16/78               65.7       8.2   10.3       830        2944      R       30        DOMESTIC SUPPLY
               10/07/78               64.3       8.3   11.5       786        2725      R       30        P-ALKA BY LIQUID
       REC COUNT -  14 FOR 13

 14            09/21/77               38.5       7.6   15.0       320        8252
               10/11/77               43.7       7.8   11.8       220        1081
               11/16/77               38.6       7.2   10.3       260        1267
```

REPORT DATE - 78/12/18.

WELL NO.	DATE MM/DD/YY	FLOWING SIGN(-)	WATER LEVEL-FT	PH	TEMP DEG-C	ALKALINT MG/L	CONDUCT MM/CM	SITE STATUS	TIME PUMPED	REMARKS
14	12/20/77		39.8	7.8	8.0	360	733			
	01/23/78		38.6	7.6	8.0	240	636	A	2	
	02/22/78		38.7	99.9	7.0	220	721	A	10	
	03/23/78		38.4	6.9	8.5	220	1182	R	5	PH BY METER.
	04/27/78		35.2	99.9	9.0	260	1312	R	2	SAMPLE FROM STOCK TANK INLE
	05/10/78		35.5	6.9	11.5	260	1124	R	2	
	06/07/78		30.7	6.9	11.5	341	1362	R	2	
	07/18/78		32.0	99.9	14.5	9999	1282	R	02	DOMESTIC,ACID CONTAMINAYED
	08/18/78		32.8	7.2	10.7	377	1254	R	15	
	09/16/78		33.2	7.3	8.0	550	1467	R	15	DOMESTIC SUPPLY
	10/07/78		34.4	7.5	10.0	342	1391	R	5	FLOODING LAWN,5 MIN PUMP

REC COUNT - 14 FOR 14

WELL NO.	DATE MM/DD/YY	FLOWING SIGN(-)	WATER LEVEL-FT	PH	TEMP DEG-C	ALKALINT MG/L	CONDUCT MM/CM	SITE STATUS	TIME PUMPED	REMARKS
15	09/21/77		999.9	9.6	17.0	120	609	F		
	10/11/77		999.9	9.4	15.0	200	749	F		
	11/17/77		999.9	9.3	14.0	300	776	F		
	12/20/77		999.9	9.1	14.0	280	660	F		
	01/24/78		999.9	9.4	7.5	160	576	F		ARTESIAN
	02/22/78	-	2.3	99.9	7.0	120	637	F		BAILED 10 GAL
	03/23/78	-	.6	8.9	6.8	180	745	G		PIPES NOT DRAINED.
	04/26/78	-	.6	99.9	7.5	100	750	G		
	05/10/78	-	.6	9.1	13.0	140	685	G		
	06/07/78	-	.6	8.8	15.0	235	888	G		
	07/17/78	-	.6	8.8	17.0	9999	853	G	0	BAILED 5 GAL,ACID CONTAMINA
	08/18/78	-	.5	8.7	15.0	244	761	G		BAILED 10 GALS
	09/27/78	-	.6	8.7	17.0	260	670	F		BAILED 10 GAL
	10/08/78	-	2.4	9.0	11.9	248	781	F		BAILED 30 GAL,LIQUID P-INDS

REC COUNT - 14 FOR 15

WELL NO.	DATE MM/DD/YY	FLOWING SIGN(-)	WATER LEVEL-FT	PH	TEMP DEG-C	ALKALINT MG/L	CONDUCT MM/CM	SITE STATUS	TIME PUMPED	REMARKS
16	09/21/77		999.9	9.3	12.0	200	738	F		
	10/11/77		999.9	9.3	11.9	140	875	F		
	11/09/77		999.9	9.1	10.0	140	852	F		
	12/20/77		999.9	9.0	10.0	240	738	F		
	01/25/78		999.9	8.9	9.0	160	692	F		ARTESIAN
	02/23/78	-	2.6	99.9	10.4	160	758	F	10	
	03/23/78	-	2.6	8.9	10.0	200	937	F		PH BY METER.
	04/26/78	-	2.3	99.9	11.8	220	945	F		
	05/10/78	-	2.6	9.7	13.0	180	848	F	5	
	06/02/78	-	2.6	8.7	12.5	218	927	F		
	07/19/78	-	2.6	8.9	13.5	9999	1013	F		PREV DEPTHS NOT ADJ,ACID CO
	08/18/78		.0	8.3	11.0	274	967	F	15	
	09/17/78	-	2.2	8.7	10.7	270	947	F	15	
	10/07/78	-	3.8	10.8	9.0	242	1021	F		LIQ P-IND.

REC COUNT - 14 FOR 16

WELL NO.	DATE MM/DD/YY	FLOWING SIGN(-)	WATER LEVEL-FT	PH	TEMP DEG-C	ALKALINT MG/L	CONDUCT MM/CM	SITE STATUS	TIME PUMPED	REMARKS
17	09/21/77		14.7	99.9	99.9	9999	999999			
	10/11/77		14.3	99.9	99.9	9999	999999			
	11/17/77		13.5	99.9	99.9	9999	999999			

```
                                                                                                        REPORT DATE -  78/12/18.
   WELL NO.       DATE        FLOWING   WATER        PH      TEMP     ALKALINT    CONDUCT    SITE     TIME                    REMARKS
                  MM/DD/YY    SIGN(-)   LEVEL-FT             DEG-C    MG/L        MM/CM      STATUS   PUMPED

17                12/20/77                 13.2     99.9     99.9       9999     999999
                  01/23/78                 13.2     99.9     99.9       9999     999999        B                  CONTINUOUS
                  02/22/78                 12.5     99.9     99.9       9999     999999        A         5
                  03/24/78                 11.1      6.8      8.3        240       2718        P                  NO DRAWDOWN, PH BY METER
                  04/26/78                 12.8     99.9     12.5        300       2704        A         2
                  05/10/78                 11.4      7.3     13.5        280       2196        A         2        HEAVY RAINS PAST 5 DAYS, WA
                  06/02/78                999.9     99.9     99.9       9999     999999        Z
                  07/18/78                 10.3     99.9     99.9       9999     999999        A                  PUMP INOPERABLE
                  08/28/78                 22.5      8.0     18.0        532        978        B                  RUNNING 3 WKS AT 450GPM
                  09/16/78                 21.5      7.2     10.2        410       3206        Z
                  10/07/78                 15.4     99.9     99.9       9999     999999        A                  ALL PUMPS OFF

         REC COUNT -   14 FOR 17

18                09/21/77                 38.5      9.4     16.0        720       1629
                  10/11/77                 42.2      9.4     14.5        520       2219
                  11/17/77                 41.2      8.3     10.0        700       1874
                  12/20/77                 41.1      9.3      9.0        660       1677
                  01/26/78                 41.1      9.2      6.0        560       1101        A                  HAND PUMP
                  02/23/78                 41.1     99.9     10.1        560       1586        A         8        WELL LOCATED BELOW RESERVOI
                  03/24/78                 40.9      8.6      9.9        540       2207        A         2        GREY COLOR, PH BY METER
                  04/27/78                 39.8     99.9     11.5        540       2316        A         2        RESERVOIR DRY
                  05/10/78                 39.9      8.6     12.0        560       1988        A         2
                  06/02/78                 39.3      8.5     12.0        698       2418        A
                  07/20/78                 39.3      8.4     14.0        688       2343        A
                  08/19/78                 39.4      7.7     14.0        756       2136        A                  HAND PUMPED 2 GALS
                  09/27/78                 39.5      8.6     13.9        780       2348        A                  HAND PUMPED 5 GAL
                  10/31/78                 39.6      8.0     10.0        780       2414        A                  PUMPED 20 GAL.COLD,GREY

         REC COUNT -   14 FOR 18

19A               10/04/77                 40.8      7.8     12.0        440       2149
                  10/11/77                 40.7      7.7     12.0        500       2149
                  11/17/77                 41.0      7.3      9.0        740       1604
                  12/20/77                 41.9      7.5     11.0        700       1381
                  01/26/78                 42.3      7.3      7.5        460       1197        A                  BOTTLE
                  02/23/78                 42.9     99.9      9.0        460       1458        A                  BAILED
                  03/24/78                 42.8      7.6     10.0        520       2386        A                  PH BY METER.
                  04/04/78                 42.3      7.1     10.8        500       3001        A
                  05/11/78                 42.9      7.6     10.8        720       2154        A
                  06/02/78                 41.0      7.4      7.4        472       2827        A                  BAILED
                  07/07/78                 41.3      7.4      8.8        504       2756        A                  SCT METER SUSPECT,BAILED SA
                  08/19/78                 41.7      7.2     11.5        774       2589        A                  BAILED
                  09/14/78                 42.0      7.3     10.5        750       2746        A        20
                  10/30/78                 42.3      7.6     10.2        760       2698        A                  BAILED

         REC COUNT -   14 FOR 19A

19B               10/04/77                 18.5      8.3     12.0        540       1612
                  10/11/77                 18.2      8.3     11.9        460       2155
                  11/17/77                 18.4      8.4     10.0        840       2130
```

WELL NO.	DATE MM/DD/YY	FLOWING SIGN(-)	WATER LEVEL-FT	PH	TEMP DEG-C	ALKALINT MG/L	CONDUCT MM/CM	SITE STATUS	TIME PUMPED	REMARKS
19B	12/20/77		18.8	8.0	10.0	760	1846			
	01/26/78		19.1	7.8	6.0	520	1652	A		BOTTLE
	02/23/78		19.5	99.9	10.1	640	2082	A		BAILED
	03/24/78		18.7	7.9	10.3	560	3000	A		PH BY METER.
	04/04/78		18.8	8.1	13.0	720	2740	A		
	05/11/78		17.9	8.1	11.0	700	2763	A		
	06/02/78		16.7	7.7	11.5	842	3134	A		BAILED
	07/08/78		17.2	7.6	11.1	856	3321	A		BAILED SAMPLE
	08/19/78		17.7	7.7	11.0	888	3441	A		BAILED
	09/14/78		18.4	7.9	12.2	860	3273	A	20	
	10/30/78		18.0	8.0	10.9	888	3353	A		BAILED
REC COUNT - 14 FOR 19B										
19C	10/04/77		25.1	7.7	12.0	440	1881			
	10/11/77		26.0	7.7	11.0	460	2971			
	11/17/77		26.1	7.6	10.0	800	2272			
	12/20/77		26.7	7.8	9.0	700	1896			
	01/26/78		26.9	7.3	4.0	560	1634	A		BOTTLE
	02/23/78		27.3	99.9	10.1	540	2110	A		BAILED
	03/24/78		25.7	7.4	10.9	720	3173	A		PH BY METER.
	04/04/78		26.4	7.4	12.3	520	3183	A		
	05/11/78		25.1	7.6	11.5	620	2984	A		
	06/02/78		23.9	7.5	12.8	820	3439	A		BAILED
	07/08/78		24.4	7.4	11.2	786	3477	A		ORANGE COLOR,BAILED SAMPLE
	08/19/78		24.5	7.3	11.5	798	3543	A		BAILED
	09/14/78		24.0	7.5	11.7	850	3482	A	20	
	10/30/78		25.5	7.5	10.5	840	3460	A		BAILED,RUST ALGAE
REC COUNT - 14 FOR 19C										
19D	10/04/77		40.0	7.8	11.0	460	1381			
	10/11/77		40.3	7.8	10.0	440	2272			
	11/17/77		41.0	8.3	8.5	700	1773			
	12/20/77		40.9	8.3	7.0	680	1382			
	01/26/78		41.8	8.2	5.0	480	1289	A		BOTTLE
	02/23/78		42.3	99.9	8.9	420	1521	A		BAILED
	03/24/78		42.6	8.9	9.2	360	1625	A		PH BY METER.
	04/04/78		40.1	8.5	10.2	400	2034	A		
	05/11/78		41.3	8.9	10.2	520	2189	A		
	06/02/78		39.5	8.7	12.0	474	2391	A		BAILED
	07/07/78		40.3	7.8	10.4	556	2810	A		BAILED SAMPLE
	08/19/78		39.9	7.8	11.0	856	2487	A		BAILED
	09/14/78		40.1	7.3	11.7	800	2710	A	20	
	10/30/78		40.6	7.8	9.9	808	2392	A		BAILED
REC COUNT - 14 FOR 19D										
19E	10/04/77		54.6	99.9	99.9	9999	999999			
	10/11/77		52.8	99.9	99.9	9999	999999			
	11/17/77		51.8	8.2	9.0	720	1896			

WELL NO.	DATE MM/DD/YY	FLOWING SIGN(-)	WATER LEVEL-FT	PH	TEMP DEG-C	ALKALINT MG/L	CONDUCT MM/CM	SITE STATUS	TIME PUMPED	REMARKS
19E	12/20/77		51.8	8.0	8.0	600	1706			
	01/26/78		52.1	8.1	7.0	400	1458	A		BOTTLE
	02/23/78		52.3	99.9	9.0	540	1765	A		BAILED
	03/24/78		40.3	7.7	7.6	420	1678	A		PH BY METER.
	04/04/78		41.6	7.3	10.5	500	2195	A		
	05/11/78		42.6	7.9	11.0	780	2073	A		
	06/02/78		40.7	7.2	12.9	612	2460	A		BAILED
	07/07/78		48.0	7.1	11.2	744	2624	A		
	08/19/78		48.6	7.7	11.5	784	3202	A		BAILED
	09/14/78		47.1	7.2	12.0	750	2566	A	20	
	10/30/78		50.6	7.3	10.2	728	2387	A		BAILED
REC COUNT - 14 FOR 19E										
2	09/19/77		10.5	7.7	16.0	400	1244			
	10/10/77		12.5	8.1	7.0	240	921			
	11/15/77		10.6	8.3	9.0	280	1239			
	12/19/77		10.7	8.2	10.0	280	994			
	01/23/78		10.3	7.6	8.0	120	898	P	10	
	02/20/78		10.4	8.1	9.5	300	834	P	5	HOLDING TANK
	03/18/78		9.9	99.9	14.0	360	1359	R		WELL ON HOUSE PRESSURE SYST
	04/11/78		9.9	7.4	9.5	320	1475	R	5	
	05/08/78		6.9	8.1	11.0	300	1243	R	5	
	06/05/78		5.9	7.9	15.5	385	1571	R	5	
	07/17/78		7.9	8.0	14.0	434	1489	R	05	ALKALINITY SUSPECT
	08/16/78		8.4	7.9	11.5	441	1499	R	15	
	09/30/78		8.1	8.1	10.2	540	1440	R	15	HOUSEHOLD WELL
	10/27/78		8.2	7.9	10.1	452	1558	A	20	RECOVERY-GOOD STATIC LEVEL
REC COUNT - 14 FOR 2										
20	09/22/77		10.0	7.6	17.5	580	1990			
	10/11/77		10.0	8.3	15.0	340	2793			
	11/17/77		9.3	8.1	11.0	500	1865			
	12/21/77		9.3	7.8	5.5	420	1433			
	01/26/78		9.3	7.4	5.0	400	1289	B		CONTINUOUS
	02/23/78		9.2	99.9	9.1	360	1658	B		HOLDING TANK, CONTINUOUS
	03/24/78		7.8	7.8	11.0	260	2073	P		NO DRAWDOWN
	04/26/78		11.3	99.9	17.1	400	3131	B		2 PUMPS RUNNING CONTINUOUSL
	05/11/78		7.8	7.9	13.0	420	2218	P		
	06/08/78		8.0	7.1	14.7	511	3448	B		
	07/20/78		8.8	8.3	20.0	530	3313	R		RUN CONTINUOUSLY
	08/21/78		9.1	7.8	17.5	538	3377	R		PUMP RUN CONSTANTLY
	10/01/78		8.7	7.8	17.0	740	3266	P		MINIMUM DISCHARGE
	10/31/78		8.4	8.0	11.0	578	3385	P		PUMPS CONTINUOUSLY
REC COUNT - 14 FOR 20										
21	09/22/77		999.9	8.4	20.0	1120	1313	F		
	10/11/77		999.9	8.4	17.0	740	1560	F		
	11/17/77		999.9	8.3	11.0	820	1133	F		

```
                                                                                                      REPORT DATE -  78/12/18.
                                                                                                            REMARKS
WELL NO.    DATE       FLOWING   WATER      PH    TEMP    ALKALINT   CONDUCT   SITE     TIME
            MM/DD/YY   SIGN(-)   LEVEL-FT         DEG-C   MG/L       MM/CM     STATUS   PUMPED

 21         12/21/77             999.9      8.3    8.0      700        1152      F
            01/23/78             999.9      8.3    8.0      600        1048      F                 ARTESIAN, CONTINUOUS
            02/24/78             999.9     99.9    9.1      740        1251      F                 WHOLETOWN USES WELL, CONTIN
            03/24/78             999.9     99.9   99.9     9999      999999      Z                 WELL TO BE DROPPED.

      REC COUNT -   7 FOR 21

 22         09/22/77              70.0      7.5   19.0     1680        3153
            10/11/77              63.4      7.4   17.5     1340        5789
            11/17/77              68.7      7.4   17.0     1300        3900
            12/21/77              64.5      7.6   14.0     1360        3107
            01/26/78              63.4      7.2   14.0     1140        2719      A         2
            02/22/78              63.8     99.9   11.8     1220        3634      A        10       HOLDING TANK
            03/28/78              58.9      7.4   12.7     1120        5214      R        10
            04/26/78              59.5      7.2   13.7     1260        5562      A        10       DRILLING NEARBY
            05/24/78              62.5      7.1   14.1     1700        5945      Z        10       DRILLING VERY NEARBY.
            06/12/78              57.7      7.3   13.8     1670        5850      R
            07/31/78              59.6      7.4   17.0     1824        5716      R                 WASHING CLOTHES
            08/29/78              63.0      7.3   14.9     1732        5750      R        10
            09/29/78              63.0      7.6   14.2     1700        5882      R        15       HOUSEHOLD SUPPLY
            10/31/78              57.5      7.3   12.2     1616        5891      R        20

      REC COUNT -  14 FOR 22

 22A        05/24/78             131.7      7.4   13.6      665        2884      A                 BAILER
            06/12/78             132.5      7.5   12.1     1460        4193      A                 BAILED
            07/31/78             132.4      7.7   12.5     1164        3602      A                 BAILED SAMPLE
            08/29/78             132.6      7.7   14.0      904        3172      A
            09/29/78             133.4      7.6   12.1      920        2907      A                 BAILED
            10/31/78             133.3      7.7   10.9     1372        4032      A                 BAILED,3 TIMES FOR ALKA.

      REC COUNT -   6 FOR 22A

 23         09/22/77              18.5      7.8   14.5      420         756
            10/11/77              22.0      7.8   13.0      340         978
            11/17/77              18.3      7.9   10.0      600         781
            12/21/77              18.3      7.9    8.5      380         628
            01/26/78              18.3      7.2    8.0      280         568      A         2
            02/22/78              18.2     99.9    9.3      240         687      A        10       HOLDING TANK
            03/24/78              17.3      7.5    9.0      280         991      R                 HOUSE SYSTEM, PH BY METER.
            04/26/78              18.0      7.6   10.8      360         861      A         7
            05/10/78              15.5      7.4   10.8      340         875      R        10
            06/08/78              15.1      7.1   12.5      418         993      R        10
            07/31/78              16.5      7.4   12.9      474        1060      R        10
            08/29/78              16.5      7.5   11.0      443         995      R        15
            09/29/78              16.6      7.6   11.5      480        1062      R        10       BARROOM SUPPLY
            10/31/78              16.1      7.7    9.1      468        1033      A        20       PH BY HORIZON

      REC COUNT -  14 FOR 23

 24         09/22/77              11.1      9.4   14.0      320        1877
```

WELL NO.	DATE MM/DD/YY	FLOWING SIGN(-)	WATER LEVEL-FT	PH	TEMP DEG-C	ALKALINT MG/L	CONDUCT MM/CM	SITE STATUS	TIME PUMPED	REMARKS
24	11/10/77		9.5	9.2	11.5	300	1907			
	12/21/77		10.0	9.2	11.0	360	1920			
	02/06/78		10.4	8.9	10.5	300	1015	A		BAILED
	02/06/78		9.9	8.9	10.5	300	1015	A		BOTTLE
	04/09/78		8.4	8.6	10.6	620	1900	A		
	05/02/78		7.8	8.7	11.5	360	2698	A		
	06/05/78		5.7	99.9	11.9	360	2371	A		
	07/31/78		8.3	8.9	13.1	358	2767	A		
	08/14/78		9.7	8.7	12.0	383	2317	A		BAILED
	09/14/78		9.4	8.8	12.0	390	2620	A	20	
	10/31/78		9.4	8.9	10.1	372	2408	A		BAILED,RUST PART.,PH BY HOR
REC COUNT - 12 FOR 24										
251A	04/20/78		21.9	8.1	10.8	240	3057	A		
	05/25/78		19.8	7.7	12.9	326	3272	A	15	PUMP TESTED WELL
	06/22/78		19.3	7.8	11.6	310	3152	A		
	07/28/78		20.0	7.7	14.0	328	3004	A		BAILED SAMPLE
	08/29/78		20.6	7.6	11.6	306	3152	A		BAILED
	09/06/78		20.7	7.7	12.2	340	3313	A	20	
	10/19/78		20.9	7.8	10.9	296	3298	A		BAILED
REC COUNT - 7 FOR 251A										
251B	04/20/78		85.2	7.3	12.2	340	2551	A		
	05/25/78		85.2	7.4	14.2	372	2863	T	15	DATA AFTER 251A WAS PUMPED
	06/22/78		85.1	7.7	12.2	420	2738	A		
	07/27/78		85.4	7.5	14.0	388	2751	A		BAILED SAMPLE
	08/29/78		85.5	7.4	13.3	386	2789	A		BAILED
	09/06/78		85.0	7.3	12.2	420	2872	A	20	
	10/19/78		85.5	7.3	11.2	396	3037	A		BAILED
REC COUNT - 7 FOR 251B										
2514A	04/20/78		137.0	8.1	11.5	180	1390	A		
	05/25/78		140.3	7.9	15.0	280	1586	A		BAILER.
REC COUNT - 2 FOR 2514A										
2514AC	04/20/78		253.5	7.0	12.2	380	1603	A		
	05/25/78		255.0	6.9	15.8	574	1811	A		BAILER.
REC COUNT - 2 FOR 2514AC										
2514B	04/20/78		132.6	6.7	11.8	240	1837	A		
	05/25/78		132.1	6.9	13.6	560	2336	A		BAILER.
REC COUNT - 2 FOR 2514B										
2514C	04/20/78		66.6	6.4	11.3	620	1863	A		
	05/25/78		34.7	6.6	16.0	754	2276	A		BAILER.

WELL NO.	DATE MM/DD/YY	FLOWING SIGN(-)	WATER LEVEL-FT	PH	TEMP DEG-C	ALKALINT MG/L	CONDUCT MM/CM	SITE STATUS	TIME PUMPED	REMARKS
REC COUNT - 2 FOR 2514C										
2515B	04/20/78		88.6	7.4	10.9	720	1552	A		
REC COUNT - 1 FOR 2515B										
252A	04/20/78		999.9	99.9	99.9	9999	999999			WELLS FLOODED
	05/25/78		999.9	99.9	99.9	9999	999999	Z		WELL UNDER WATER
	06/28/78		999.9	99.9	99.9	9999	999999	Z		FLOODED
	07/28/78		999.9	99.9	99.9	9999	999999	Z		WELLFLOODED
	08/29/78		999.9	99.9	99.9	9999	999999	Z		FLOODED
	09/07/78		27.5	7.1	12.0	620	2001	Z	8	FLOODED CONDITIONS
	10/19/78		4.6	7.1	10.5	546	2101	A		BAILED-STREAM 15 FT AWAY
REC COUNT - 7 FOR 252A										
252B	04/20/78		999.9	99.9	99.9	9999	999999			WELLS FLOODED
	05/25/78		999.9	99.9	99.9	9999	999999	Z		WELL UNDER WATER
	06/28/78		999.9	99.9	99.9	9999	999999	Z		FLOODED
	07/28/78		999.9	99.9	99.9	9999	999999	Z		WELL FLOODED
	08/29/78		999.9	99.9	99.9	9999	999999	Z		FLOODED
	09/07/78		82.2	7.2	13.5	560	2890	Z	5	FLOODED CONDITIONS
	10/19/78		49.4	7.4	11.0	576	2183	A		BAILED-STREAM 15 FT AWAY
REC COUNT - 7 FOR 252B										
252C	04/20/78		999.9	99.9	99.9	9999	999999			WELLS FLOODED
	05/25/78		124.7	8.2	15.0	368	2526	Z		BAILER NEARBY AREA SUBMERGE
	06/23/78		124.5	8.2	14.9	372	2506	Z		AREA FLOODED
	07/27/78		124.8	8.2	16.0	372	2488	Z		AREA FLOODED.BAILED SAMPLE
	08/29/78		124.8	7.8	14.8	460	2523	Z		FLOODING INFLUENCE
	09/07/78		124.6	8.1	14.8	460	2523	A	2	FLOODED CONDITIONS
	10/19/78		124.8	8.3	12.0	372	2552	A		BAILED
REC COUNT - 7 FOR 252C										
253A	04/20/78		226.9	8.4	12.9	320	1060	A		
	05/25/78		227.7	7.7	14.8	624	1147	A		BAILER.
	06/23/78		227.9	8.3	14.5	466	1077	A		
	07/27/78		228.1	8.3	16.5	396	1847	A		BAILED SAMPLE
	08/30/78		227.6	8.2	15.0	343	1891	A		BAILED
	09/07/78		223.1	7.2	15.0	390	1929	A		BAILED, BLACK WATER
	10/20/78		115.1	8.1	12.5	462	1470	A		BLACK WATER-BAILED
REC COUNT - 7 FOR 253A										
253B	04/20/78		151.2	8.2	13.5	120	1883	A		
	05/25/78		143.4	8.2	15.0	320	2005	A		BAILER.
	06/23/78		151.3	8.4	16.8	316	1872	A		
	07/27/78		151.4	8.3	17.0	333	1816	A		BAILED SAMPLE

```
                                                                                                     REPORT DATE -  78/12/18.
 WELL NO.      DATE      FLOWING   WATER        PH     TEMP     ALKALINT    CONDUCT   SITE     TIME                REMARKS
               MM/DD/YY  SIGN(-)   LEVEL-FT            DEG-C    MG/L        MM/CM     STATUS   PUMPED

253B           08/30/78             152.0       8.1    15.0       309        1967       A                BAILED
               09/07/78             151.3       8.2    14.0       280        2007       A                BAILED
               10/20/78             151.3       8.1    12.7       300        1975       A                BAILED

      REC COUNT -    7 FOR 253B

253C           04/20/78             115.3       7.8    14.9       240        1691       A
               05/25/78             114.9       7.4    16.0       344        1866       A                BAILER.
               06/23/78             115.3       7.8    15.8       356        1873       A
               07/27/78             115.1       7.9    16.0       487         995       A                BAILED SAMPLE
               08/30/78             115.3       7.6    13.5       480        1176       A                BAILED
               09/07/78             114.7       8.1    13.5       480        1176       A                BAILED
               10/20/78             223.0       7.3    14.0       344        2071       A                BAILED

      REC COUNT -    7 FOR 253C

254A           06/28/78              33.7      99.9    12.5       544        1033       A
               07/27/78              34.9       7.6    13.2       542        1025       A                BAILED SAMPLE
               08/30/78              35.4       7.2    10.0       530        1164       A                BAILED
               09/08/78              35.4       7.1    11.2       530        1126       A                BAILED
               10/10/78              35.2       7.1    10.2       520        1765       A                BAILED

      REC COUNT -    5 FOR 254A

254B           06/28/78              48.3      99.9    12.1       580        1112       A
               07/27/78              48.6       7.8    14.0       606        1048       A                BAILED SAMPLE
               08/30/78              48.0       6.9    10.0       552        1136       A                BAILED,PHTAKEN 3 TIMES
               09/08/78              49.0       6.9    11.6       560        1970       A                BAILED
               10/10/78              42.2       6.9    10.5       550        1261       A                BAILED

      REC COUNT -    5 FOR 254B

254C           06/28/78             222.2       7.8    15.3       290        2019       A
               07/27/78             107.5       7.7    16.0       320        1990       A                BAILED SAMPLE
               08/30/78             107.5       7.6    12.8       279        1995       A                BAILED
               09/08/78             107.1       7.9    14.0       280        2123       A         4
               10/20/78             107.3       8.1    13.0       284        2244       A                BAILED

      REC COUNT -    5 FOR 254C

255A           04/20/78              29.0       8.7    11.2       360         989       A
               05/23/78              29.2       6.9    12.4       495        1049       A
               06/23/78              28.7       8.5    12.1       496        1031       A                SLIGHTLY MUDDY
               07/08/78              28.8       7.3    11.4       490        1093       A                BAILED SAMPLE
               08/30/78              28.5       6.9    10.0       468        1207       A                BAILED
               09/08/78              28.4       6.9    10.8       490        1181       A        20
               10/20/78              28.0       6.8    10.2       460        1426       A                BAILED

      REC COUNT -    7 FOR 255A

255B           04/20/78              56.6       7.6    11.1       320         882       A
```

WELL NO.	DATE MM/DD/YY	FLOWING SIGN(-)	WATER LEVEL-FT	PH	TEMP DEG-C	ALKALINT MG/L	CONDUCT MM/CM	SITE STATUS	TIME PUMPED	REMARKS
255B	05/23/78		55.4	7.5	13.3	322	958	A		
	06/23/78		55.2	7.6	11.8	192	891	A		
	07/08/78		55.2	7.4	11.9	202	970	A		BAILED SAMPLE
	08/30/78		54.7	7.4	11.5	332	851	A		BAILED
	09/08/78		54.0	7.5	11.8	400	1053	A	12	
	10/20/78		53.4	7.4	10.4	370	1095	A		BAILED
REC COUNT - 7 FOR 255B										
255C	04/20/78		106.0	7.7	12.0	200	2136	A		
	05/23/78		107.2	7.7	12.9	278	1544	A		
	06/23/78		107.3	7.5	13.0	286	2192	A		
	07/08/78		107.4	7.4	13.2	292	2275	A		BAILED SAMPLE
	08/30/78		107.3	7.4	11.5	283	2316	A		BAILED
	09/08/78		107.1	7.7	12.7	280	2370	A	5	
	10/20/78		107.2	7.2	12.0	280	2525	A		BAILED
REC COUNT - 7 FOR 255C										
256A	06/28/78		96.2	11.4	12.2	226	1042	A		CLOUDY.
	07/08/78		96.1	11.0	15.9	220	1059	A		BAILED SAMPLE
	08/30/78		96.8	11.2	11.0	228	1174	A		BAILED
	09/07/78		96.9	11.0	12.5	250	1324	A		BAILED, CLOUDY WATER
	10/19/78		97.6	11.2	10.2	350	1709	A		BAILED-CLEAR
REC COUNT - 5 FOR 256A										
256B	06/28/78		59.5	7.1	16.8	794	1542	A		CLOUDY.
	07/08/78		58.9	7.1	12.8	778	1575	A		CLOUDY WATER BAILED SAMPLE
	08/30/78		59.6	6.8	11.5	708	1567	A		BAILED, CLOUDY WATER
	09/07/78		58.5	7.1	12.5	750	1629	A		BAILED, CLOUDY WATER
	10/19/78		58.4	7.1	11.5	750	1608	A		BAILED-CLEAR-STINKS
REC COUNT - 5 FOR 256B										
256C	06/28/78		64.0	6.0	12.2	616	1375	A		
	07/08/78		67.7	6.9	14.0	674	1307	A		MUDDY WATER BAILED SAMPLE
	08/30/78		64.5	7.0	11.0	633	1216	A		BAILED, MUDDY WATER
	09/07/78		64.5	7.1	13.0	550	1318	A		
	10/19/78		66.8	6.8	11.5	626	1362	A		BAILED-CASING,WATER,MUD
REC COUNT - 5 FOR 256C										
256D	06/28/78		38.8	10.4	12.0	72	507	A		
	07/08/78		38.3	10.7	11.2	62	492	A		BAILED SAMPLE
	08/30/78		37.9	10.3	11.0	71	508	A		BAILED
	09/07/78		37.6	9.2	12.0	40	524	A		
	10/19/78		37.7	9.5	11.0	14	338	A		BAILED
REC COUNT - 5 FOR 256D										

```
WELL NO.       DATE       FLOWING    WATER       PH     TEMP     ALKALINT   CONDUCT   SITE     TIME                REMARKS
               MM/DD/YY   SIGN(-)    LEVEL-FT           DEG-C    MG/L       MM/CM     STATUS   PUMPED

256E           06/28/78                 80.4     7.4    13.5         370       732      A
               07/08/78                 80.4     7.3    12.0         224       604      A               BAILED SAMPLE
               08/30/78                 81.7     7.3    11.0         218       663      A               BAILED
               09/07/78                 81.6     7.2    12.5         210       662      A               BAILED
               10/19/78                 82.6     7.2    11.2         220       629      A               BAILED-WATER HAD DEAD ANIMA

     REC COUNT -   5 FOR 256E

256F           06/28/78                 38.5     7.1    13.0         218       567      A               GREENTINT
               07/08/78                 37.9     7.2    12.3         358       772      A               BAILED SAMPLE
               08/30/78                 37.5     7.2    11.0         337       718      A               BAILED
               09/06/78                 37.2     7.1    11.8         360       837      A               BAILED
               10/19/78                 37.2     7.1    11.0         336       801      A               BAILED

     REC COUNT -   5 FOR 256F

258A           04/20/78                193.4     7.3    12.7         300      1237      A
               05/25/78                192.8     7.4    14.6         368      1382      A               BAILER.
               06/23/78                191.8     7.3    16.4         392      1295      A
               07/27/78                198.6     7.3    16.5         409      1342      A               BAILED SAMPLE
               08/29/78                193.6     7.2    14.2         338      1393      A               BAILED
               09/06/78                193.1     7.3    15.0         340      1333      A               BAILED
               10/18/78                194.0     7.4    13.0         350      1370      A               BAILED-WATER STINKS

     REC COUNT -   7 FOR 258A

258B           04/20/78                128.3    11.8    11.8         340      2162      A
               05/25/78                127.7     9.6    17.0         348      2047      A               BAILER.
               06/23/78                128.6    11.5    15.0         330      2259      A
               07/27/78                127.3    11.3    15.0         294      1929      A               BAILED SAMPLE
               08/29/78                127.5    11.2    14.0         274      1981      A               BAILED
               09/06/78                128.5    11.6    15.2         350      2048      A               BAILED
               10/18/78                127.4    11.3    12.5         328      2251      A               BAILED

     REC COUNT -   7 FOR 258B

258C           04/20/78                 72.7     7.0    11.1         400      1088      A
               05/25/78                 64.0     7.0    14.1         480      1176      A               BAILER.
               06/24/78                 72.1     7.1    13.3         490      1128      A
               07/27/78                 72.2     7.0    13.5         450      1150      A               BAILED SAMPLE
               08/29/78                 72.2     7.0    13.2         486      1157      A               BAILED
               09/06/78                 71.7     7.0    14.5         500      1128      A         3
               10/18/78                 72.3     7.2    11.3         490      1096      A         3     SET PUMP AT 95 FT.LOST PUMP

     REC COUNT -   7 FOR 258C

26             03/29/78      -           4.2     9.0    14.9         240      1068      F
               04/26/78      -           3.2    99.9    14.8         300      1083      F               ALKA BY MADE UP SOLUTION
               05/09/78      -           3.2     8.8    14.0         400      1035      F
               06/06/78      -           3.2     9.0    16.0         444      1119      F
               07/18/78      -           3.2     8.8    15.0         497      1142      F
```

WELL NO.	DATE MM/DD/YY	FLOWING SIGN(-)	WATER LEVEL-FT	PH	TEMP DEG-C	ALKALINT MG/L	CONDUCT MM/CM	SITE STATUS	TIME PUMPED	REMARKS
26	08/18/78	-	8.2	8.9	14.0	503	1165	F	15	
	09/16/78	-	4.9	9.1	12.0	530	1182	F		
	10/07/78	-	6.2	9.1	13.7	468	1159	F		LIQ P-IND
REC COUNT - 8 FOR 26										
26A	03/29/78	-	9.4	8.9	11.9	280	970	F		
REC COUNT - 1 FOR 26A										
27	03/29/78		11.1	99.9	12.4	580	3320	A		WATER CLOUDY.
	04/26/78		10.2	99.9	99.9	9999	999999	A		POWER OUT
	05/10/78		10.2	99.9	99.9	9999	999999	A		PUMP BROKEN
	07/18/78		999.9	7.1	17.0	388	2071	Z		NEW WELL NOT PREPARED DEPTH
	10/07/78		24.6	8.3	11.0	770	2833	A		LIQ P-IND, PUMPED DRY.
REC COUNT - 5 FOR 27										
27A	08/28/78		16.2	8.9	11.9	328	3233	A		HAND PUMPED 5 GALS
	09/17/78		24.6	8.3	10.0	860	2911	A		DARK GREY WATER
REC COUNT - 2 FOR 27A										
28A	03/30/78		22.2	8.0	10.6	200	2235	A		
	04/26/78		22.0	99.9	11.5	300	2289	A	5	
	05/10/78		21.7	8.0	14.0	300	2046	A	5	
	06/07/78		21.9	7.7	12.3	351	2331	A		
	07/19/78		21.3	8.1	16.0	598	1990	R		
	08/18/78		20.9	8.1	11.0	368	2238	A	15	
	09/27/78		21.0	8.1	13.5	360	2157	A	15	
	10/07/78		21.1	8.1	10.2	348	2811	A	15	LIQ P-IND
REC COUNT - 8 FOR 28A										
28B	03/30/78		15.1	9.0	14.9	280	788	Z		DISCHARGED INTERMITTENTLY
	04/26/78		17.0	99.9	14.8	280	764	P		NO RECOVERY TAKEN
	05/10/78		17.2	9.1	14.9	260	763	P	20	
	06/07/78		17.8	8.8	14.5	330	769	B		
	07/19/78		18.0	9.1	16.5	598	738	Z		INTERMITTENT PUMPING
	08/18/78		17.1	8.7	16.0	378	746	Z		DISCHARGE PULSATING
	09/17/78		16.8	8.8	14.1	360	775	P		
	10/07/78		11.4	9.0	13.2	330	1118	A	15	LIQ P-IND, PUMP OFF.
REC COUNT - 8 FOR 28B										
29	03/28/78	-	21.9	8.2	15.5	700	1885	F		GAS IN WATER
	04/27/78	-	9.7	99.9	16.2	560	1858	F		
	05/11/78	-	10.4	8.1	16.0	840	1835	F	5	4.5 PSI
	06/08/78	-	10.4	7.9	17.0	1000	2011	F		
	07/18/78	-	19.1	8.1	15.5	930	2011	Z		BAD PRESSURE GAGE
	08/28/78		999.9	8.1	17.0	923	1889	F		GAUGE BROKEN

WELL NO.	DATE MM/DD/YY	FLOWING SIGN(-)	WATER LEVEL-FT	PH	TEMP DEG-C	ALKALINT MG/L	CONDUCT MM/CM	SITE STATUS	TIME PUMPED	REMARKS
29	09/31/78		999.9	8.3	16.0	1180	1866	F		
	10/07/78	-	21.6	8.2	15.9	1100	1807	F		
REC COUNT - 8 FOR 29										
3	09/19/77		16.8	8.5	11.5	400	2384			
	10/10/77		16.6	8.8	10.0	220	1704			
	11/15/77		16.3	8.7	11.0	240	2211			
	12/19/77		15.8	9.0	11.5	380	1362			
	01/23/78		15.8	9.2	9.0	380	1458	A	2	
	02/20/78		15.1	8.7	9.3	220	1577	A		BOTTLE
	03/18/78		14.2	99.9	10.0	320	3124	A		
	04/12/78		13.0	8.3	9.0	280	3063	A		PH WITH PAPER, BAILED SAMPL
	05/08/78		13.4	8.3	11.0	280	2625	A		THIEF SAMPLE
	06/05/78		12.1	8.6	11.5	380	3304	A		BAILED
	07/17/78		13.9	8.7	12.5	387	3178	A	0	BAILED SAMPLE
	08/16/78		14.7	8.6	10.5	389	3222	A		BAILED
	09/15/78		15.1	7.4	6.8	690	4475	A	20	
	10/25/78		14.5	8.1	9.1	620	3346	A		RUST PARTICLES,CAVED,BAILED
REC COUNT - 14 FOR 3										
30	06/28/78		9.0	99.9	12.4	472	2722	A		BAILED-NEW WELL
	07/31/78		9.9	7.8	12.2	462	4662	A		BAILED SAMPLE
	08/19/78		8.9	7.3	12.0	478	2821	A		BAILED
	09/14/78		9.1	7.5	12.0	480	2485	A	20	
	10/30/78		9.3	99.9	10.8	460	2390	A		BAILED
REC COUNT - 5 FOR 30										
4	09/19/77		23.0	7.7	16.0	950	3110			
	10/10/77		22.5	7.7	10.0	440	2130			
	11/15/77		22.3	7.6	10.0	460	1704			
	12/19/77		21.9	7.8	8.5	580	1773			
	01/23/78		21.9	7.8	9.0	520	1750		2	
	02/20/78		22.1	7.7	9.4	400	2006	P	180	
	03/19/78		23.4	7.6	10.0	420	4474	A	5	
	04/12/78		20.1	6.8	10.0	440	4545	A	5	PH WITH PAPER
	05/08/78		21.6	7.6	12.0	440	3493	R	5	
	06/05/78		17.4	7.1	14.0	438	4519	A	5	
	07/17/78		18.8	7.5	13.0	698	4555	A	05	ALKALINITY SUSPECT
	08/16/78		19.6	7.4	11.4	702	4680	A	15	
	09/30/78		20.0	7.8	11.0	810	4671	A	15	
	10/25/78		19.8	7.9	9.8	740	4869	A	15	COLD DAY
REC COUNT - 14 FOR 4										
40	10/04/77		999.9	7.3	99.9	160	262	F		
	11/03/77		999.9	8.6	10.0	140	352	F		
	12/06/77		999.9	8.3	12.0	120	376	F		
	01/10/78		999.9	8.1	11.0	140	331	F	0	ARTESIAN

```
                                MONTHLY MONITORING DATA-POWDER RIVER BASIN

                                                                                       REPORT DATE -  78/12/18.

  WELL NO.     DATE       FLOWING   WATER     PH    TEMP    ALKALINT  CONDUCT  SITE    TIME          REMARKS
               MM/DD/YY   SIGN(-)   LEVEL-FT        DEG-C   MG/L      MM/CM    STATUS  PUMPED

 40            02/08/78     -        22.5     7.8    8.1      160       350     F              CONTINUOUS
               03/16/78     -        19.5    99.9   13.1      120       495     G              FLOWING ARTESIAN WELL WITHI
               04/11/78     -        18.3     7.7   14.3      100       491     F
               05/12/78     -        17.0    99.9   13.8      140       494     G              PH LOWER THAN PAPER RANGE.
               06/09/78     -        16.5    99.9   14.9      176       496     G              PH BELOW PAPER RANGE
               07/26/78     -        18.3     7.8   14.0      188       530     G              FLOWING AT 2.14 GPM
               08/20/78     -        17.8     7.2   99.9      200    999999     F       30     SCT OUT
               09/25/78     -        17.7     7.6   16.0      200       528     F       30
               10/13/78     -        15.8     8.1   12.5      182       490     F

       REC COUNT -  13 FOR 40

 41            11/03/77              47.5     9.6    9.0       60       379
               12/06/77              48.2     9.3   13.0       60       287
               01/10/78              48.3     8.2    9.0       80       277              0
               02/08/78              48.6     8.9    5.0       60       306     A              BOTTLE
               03/16/78              51.5    99.9   10.4       40       407     A              THIEF SAMPLED.
               04/11/78              48.5     6.7   11.3      100       733     A
               05/12/78              46.7    99.9   10.3      180       958     A              WATER COLORED YELLOW PH LOW
               06/09/78              46.9    99.9   12.6      274       897     A              PH BELOW PAPER RANGE
               07/26/78              46.3     7.0   11.3      236      1027     A
               08/20/78              45.6     6.8   99.9      262    999999     A              BAILED SCT OUT,PH DIF TO CA
               09/25/78              44.1     6.3   12.7      248      1053     A              BAILED
               10/13/78              44.2     6.9    9.9      250       968     A

       REC COUNT -  12 FOR 41

 42            10/04/77             999.9     7.8   99.9       80       290     F
               11/03/77             999.9     8.1    8.0      120       509     F
               12/06/77             999.9     8.3   14.0      100       356     F
               01/10/78             999.9     7.8   10.0      140       345     F        0     ARTESIAN
               02/08/78     -        18.5     7.4    7.0      160       304     F              CONTINUOUS
               03/16/78     -        17.9    99.9   10.2       80       550     F
               04/09/78     -        17.7     7.1   10.7      100       543     F
               05/12/78     -        17.7    99.9   10.7      100       550     F              PH LOWER THAN PAPER RANGE.
               06/09/78     -        16.3    99.9   11.9      180       552     F              PH BELOW PAPER RANGE
               07/26/78     -        17.9     7.7   11.0      182       566     F              FLOWING AT 13.15 GPM
               08/20/78     -        18.8     7.8   99.9      200    999999     F       30     SCT OUT
               09/25/78     -        18.8     7.4   12.0      185       678     F
               10/13/78             999.9     7.7   10.0      182      2982     F              NO DEPTH GATE LOCKED

       REC COUNT -  13 FOR 42

 43            10/04/77               8.2     8.0   99.9      180       250
               11/03/77               6.9     9.6    8.0      160       389
               12/06/77               7.5     8.1    6.0      120       330
               01/10/78               7.5     7.8    2.0      120       319              0
               02/07/78               7.4     7.7   10.0      180       262     A        1
               03/16/78               7.5    99.9   10.2      160       433     A       10
               04/11/78               6.6     7.3   10.6      160       442     A       10
               05/04/78               6.8     7.5   10.8      220       430     A       10
```

```
                                                                                                  REPORT DATE -  78/12/18.
 WELL NO.        DATE       FLOWING    WATER        PH     TEMP     ALKALINT     CONDUCT    SITE       TIME                  REMARKS
                 MM/DD/YY   SIGN(-)    LEVEL-FT            DEG-C    MG/L         MM/CM      STATUS     PUMPED

43               06/09/78                  6.7    99.9     99.9       9999      999999        A                   PUMP DOES NOT OPERATE
                 07/26/78                  6.1    99.9     99.9       9999      999999        A
                 08/20/78                 10.4     7.8     99.9        134      999999        P           30      SCT OUT,RECOVERY DONE

         REC COUNT -  11 FOR 43

43A              09/25/78                 14.6     7.3     15.0        240         615        P                   WELL RELOCATED
                 10/12/78                 12.1     7.1     10.0        188         419        A                   NEW WELL 20 FT N OF #40 WEL

         REC COUNT -   2 FOR 43A

44               10/04/77                999.9     9.4     99.9         40         310
                 11/03/77                219.0    10.2     10.0         20         438
                 12/06/77                218.8    10.2      7.0         40         376
                 01/09/78                216.3    10.2      8.0         40         425                     0
                 02/07/78                214.5    10.5      6.0         20         346        A                   BOTTLE
                 03/07/78                208.8    99.9     10.5         20         700        A                   THIEF SAMPLED
                 04/11/78                204.9     9.6     11.8         20         448        A
                 05/11/78                202.0    99.9     10.5         10         434        A                   PH LOWER THAN PAPER RANGE
                 06/09/78                199.5     8.9     14.1         44         411        A                   PH BY PAPER
                 07/26/78                199.9     9.4     12.6         40         739        A
                 08/20/78                198.4     9.1     99.9         40      999999        A                   BAILED, SCT OUT
                 09/25/78                196.4     9.3     12.5         38        1205        A                   BAILED
                 10/12/78                195.5     9.3     10.2         38         353        A                   BAILED

         REC COUNT -  13 FOR 44

45               10/04/77                160.0     7.3     99.9        320         800
                 11/03/77                159.8     8.0      8.5        240        1019
                 12/06/77                159.0     8.3      8.0        180         673
                 01/10/78                159.7     7.9      8.0        180         718                     0
                 02/07/78                159.5     7.6     11.0        280         566        A           10
                 03/16/78                159.7    99.9     10.0        100        1420        A            8
                 04/11/78                159.3     6.7     10.8        240        1361        A           20
                 05/04/78                159.2     7.1     10.6        360        1397        A           15
                 06/09/78                159.7    99.9     11.6        382        2622        A           16      PH BELOW PAPER RANGE
                 07/26/78                160.9     7.3     13.1        400        1700        R            3      WINDMILL ON, SPORADIC WIND
                 08/20/78                161.6     7.3     99.9        380      999999        P           12      SCT OUT,PH DIF TO CALIBRATE
                 09/25/78                162.2     7.1     12.5        360        1695        P                   5 MIN. RECOVERY
                 10/12/78                161.4     7.3     10.0        388        1420        P

         REC COUNT -  13 FOR 45

46               01/09/78                999.9     7.7      8.0        160         464                     1
                 02/07/78                141.8     7.5      7.5        180         470        P           30
                 03/07/78                142.9    99.9     10.1        100        1246        A           10
                 04/11/78                141.4     6.4     10.7        120        1198        A           15
                 05/11/78                144.5    99.9     10.4        120         688        P                   NO RECOVERY PH LOWER THAN P
                 06/09/78                999.9    99.9     12.0        186         662        O                   PH BELOW PAPER RANGE
                 07/26/78                142.3     6.8     11.7        180        1111        B                   WINDMILL
                 08/20/78                999.9     6.6     99.9        182      999999        O                   SCT OUT, OBSTRUCTION IN WEL
```

REPORT DATE - 78/12/18.

WELL NO.	DATE MM/DD/YY	FLOWING SIGN(-)	WATER LEVEL-FT	PH	TEMP DEG-C	ALKALINT MG/L	CONDUCT MM/CM	SITE STATUS	TIME PUMPED	REMARKS
46	09/25/78		143.7	7.2	12.0	180	839	P		
	10/12/78		143.4	7.4	9.8	170	635	P		

REC COUNT - 10 FOR 46

WELL NO.	DATE MM/DD/YY	FLOWING SIGN(-)	WATER LEVEL-FT	PH	TEMP DEG-C	ALKALINT MG/L	CONDUCT MM/CM	SITE STATUS	TIME PUMPED	REMARKS
47	10/05/77		91.4	8.3	99.9	560	1200			
	11/03/77		99.2	8.2	10.0	600	1988			
	12/07/77		99.3	8.5	4.0	600	1403		0	
	01/11/78		72.5	8.3	8.0	480	1011	A	5	
	02/08/78		83.4	8.0	99.9	440	775	A	5	
	03/08/78		84.4	99.9	99.9	9999	999999	A		WINDMILL FROZEN
	04/10/78		72.6	7.7	10.9	480	2300	A	20	
	05/03/78		76.8	7.7	11.8	920	2567	P		WAIT 30 MIN FOR DEPTH, NO R
	06/07/78		87.6	7.8	12.4	880	2297	P		PH BY PAPER
	07/25/78		89.5	8.0	13.2	790	2328	P		SEE RECOVERY DATA
	08/16/78		89.2	99.9	99.9	9999	999999	P		FORGOT PARAMETERS,REC DONE
	09/26/78		83.3	99.9	99.9	9999	999999	A		DRY LEATHERS
	10/11/78		82.9	99.9	99.9	9999	999999	A		PUMP NOT WORKING

REC COUNT - 13 FOR 47

WELL NO.	DATE MM/DD/YY	FLOWING SIGN(-)	WATER LEVEL-FT	PH	TEMP DEG-C	ALKALINT MG/L	CONDUCT MM/CM	SITE STATUS	TIME PUMPED	REMARKS
48	10/05/77		89.2	7.8	99.9	240	1500			
	11/04/77		92.2	8.2	9.0	480	2684			
	12/07/77		90.1	8.0	10.0	420	1775			
	01/12/78		89.3	7.4	10.0	420	1136	A	10	
	02/09/78		90.6	7.4	6.0	520	1573	A	5	
	03/08/78		92.2	99.9	10.9	360	1732	P		NO RECOVERY MEASUREMENTS MA
	04/10/78		999.9	7.4	10.3	420	3127	O		
	05/03/78		97.5	7.2	11.1	660	3293	P		WAIT 30 MIN FOR DEPTH, NO R
	06/08/78		89.6	99.9	12.2	444	2671	A	15	PH BELOW PAPER RANGE
	07/25/78		88.2	7.5	12.0	400	2499	A	15	PUMPED AT 2.58GPM AVG
	08/17/78		87.4	7.7	99.9	410	999999	A	19	SCT OUT
	09/26/78		97.2	7.2	16.0	670	3085	P		ALKALINITY CHECKED 3 TIMES
	10/11/78		87.9	7.4	13.5	582	3171	P		WINDMILL NOT ON

REC COUNT - 13 FOR 48

WELL NO.	DATE MM/DD/YY	FLOWING SIGN(-)	WATER LEVEL-FT	PH	TEMP DEG-C	ALKALINT MG/L	CONDUCT MM/CM	SITE STATUS	TIME PUMPED	REMARKS
49	10/05/77		999.9	7.6	99.9	260	1100			
	11/04/77		27.7	7.9	13.0	280	1762			
	12/07/77		999.9	8.0	11.0	260	1271			
	01/12/78		999.9	99.9	99.9	9999	999999	Z		PUMP BROKEN
	03/08/78		28.1	99.9	99.9	9999	999999	A		WINDMILL FROZEN
	04/09/78		27.8	99.9	99.9	9999	999999	A		PUMP BROKEN
	05/03/78		999.9	7.4	11.2	320	2088	B		NO RECOVERY.
	06/08/78		33.9	99.9	12.4	376	2018	P		PH BELOW PAPER RANGE
	07/26/78		25.5	99.9	99.9	9999	999999	A		MILL BROKEN
	08/17/78		25.1	99.9	99.9	9999	999999	A		MILL BROKEN
	09/26/78		26.1	99.9	99.9	9999	999999	A		MILL BROKEN
	10/11/78		25.1	7.4	12.9	370	2251	P		PUMP FIXED

REC COUNT - 12 FOR 49

REPORT DATE - 78/12/18.

WELL NO.	DATE MM/DD/YY	FLOWING SIGN(-)	WATER LEVEL-FT	PH	TEMP DEG-C	ALKALINT MG/L	CONDUCT MM/CM	SITE STATUS	TIME PUMPED	REMARKS
5	09/19/77		39.1	7.7	13.5	420	1804			
	10/10/77		39.3	7.7	9.0	280	1677			
	11/15/77		39.1	8.1	10.0	280	2130			
	12/19/77		39.1	8.2	4.0	440	1568			
	01/23/78		39.2	8.0	9.0	300	1167	A	1	
	02/20/78		38.9	7.8	10.5	320	1120	A	2	
	03/19/78		38.1	7.8	7.2	220	2597	A	1	
	04/12/78		36.6	7.2	11.0	160	1409	A	5	PH WITH PAPER
	05/08/78		32.4	8.2	13.0	140	1892	A	5	
	06/05/78		34.0	7.5	15.0	431	3618	A	5	
	07/17/78		35.3	7.7	15.0	504	3554	A	05	
	08/16/78		35.9	7.3	15.0	494	3554	A	15	
	09/30/78		36.1	7.4	13.0	420	3263	A	15	
	10/25/78		36.1	7.3	11.5	454	3734	A	10	COLD DAY
REC COUNT - 14 FOR 5										
50	10/05/77		55.5	8.3	99.9	200	850			
	11/04/77		55.8	8.6	14.0	560	1282			
	12/07/77		61.1	8.5	9.5	460	1151			
	01/12/78		56.5	8.2	10.0	500	1022	A	5	
	02/08/78		55.6	8.3	8.0	560	1212	A	5	
	03/09/78		55.8	99.9	11.9	520	1387	A	15	
	04/10/78		63.4	7.6	11.3	420	1425	A	15	
	05/03/78		67.4	7.9	10.9	720	1399	A	5	
	06/08/78		57.4	99.9	99.9	9999	999999	A		PUMP BROKEN
	07/26/78		52.4	8.5	13.3	714	1444	A	5	SHORT PUMPING AFFECTED TEMP
	08/17/78		55.7	8.1	99.9	824	999999	A		SCT OUT
	09/26/78		55.7	8.2	13.0	800	1422	A		
	10/11/78		55.6	8.1	13.9	762	1544	A		
REC COUNT - 13 FOR 50										
51	10/06/77		73.5	7.7	99.9	240	2250			
	11/09/77		999.9	7.5	10.0	260	4545			
	12/08/77		73.3	7.3	6.0	240	4407			
	03/09/78		69.0	99.9	99.9	9999	999999	A		WINDMILL FROZEN
	04/12/78		68.0	99.9	99.9	9999	999999	A		PUMP BROKEN
	05/04/78		67.9	99.9	99.9	9999	999999	A		PUMP BROKEN
	06/10/78		999.9	99.9	11.4	312	1434	O		PH BELOW PAPER RANGE
	07/27/78		999.9	7.3	11.4	306	1694	O		PUMPED AT 1.68GPM AVG,NO AC
	08/18/78		69.0	7.7	99.9	332	999999	P	30	SCT OUT
	09/27/78		69.6	7.3	12.0	335	1545	P		
	10/12/78		69.6	6.8	10.0	328	1633	P		
REC COUNT - 11 FOR 51										
52	10/06/77		37.6	7.1	99.9	200	490			
	11/09/77		32.6	7.0	10.0	180	724			
	12/08/77		32.8	6.9	6.0	170	755			
	03/09/78		32.7	99.9	99.9	9999	999999	A		WINDMILL FROZEN

MONTHLY MONITORING DATA-POWDER RIVER BASIN

REPORT DATE - 78/12/18.

WELL NO.	DATE MM/DD/YY	FLOWING SIGN(-)	WATER LEVEL-FT	PH	TEMP DEG-C	ALKALINT MG/L	CONDUCT MM/CM	SITE STATUS	TIME PUMPED	REMARKS
52	04/12/78		32.9	99.9	99.9	9999	999999	A		PUMP BROKEN
	05/04/78		32.6	99.9	99.9	9999	999999	A		PUMP BROKEN
	06/10/78		33.2	99.9	10.2	300	890	P		PH BELOW PAPER RANGE
	07/27/78		29.9	7.5	10.5	252	1008	A	16	PUMPED AT 2.68GPM AVG
	08/18/78		32.5	7.6	99.9	290	999999	A	20	SCT OUT
	09/27/78		34.4	7.3	11.0	310	1001	P		
	10/12/78		33.2	7.2	9.0	320	1021	P		
REC COUNT - 11 FOR 52										
53	10/06/77		17.1	7.2	99.9	200	510			
	11/09/77		5.3	8.1	10.0	160	980			
	12/08/77		17.3	8.0	6.0	140	1023			
	03/09/78		9.8	99.9	99.9	9999	999999	A		WINDMILL FROZEN
	04/12/78		9.2	99.9	99.9	9999	999999	A		PUMP BROKEN
	05/11/78		11.3	99.9	10.4	300	8008	P		BANK FULL EMBAYMENT NEAR C1
	06/10/78		7.8	7.4	9.7	370	8161	A	20	PH BY PAPER
	07/27/78		9.9	7.5	11.8	430	9188	P		SEE RECOVERY DATA
	08/18/78		10.6	7.9	99.9	420	999999	A	30	SCT OUT,RECOVERY DONE
	09/27/78		21.3	7.7	11.0	420	8326	P		
	10/12/78		12.6	7.5	9.0	418	8752	P		
REC COUNT - 11 FOR 53										
54	10/06/77		186.0	8.9	99.9	60	500			
	11/09/77		187.3	9.0	8.5	60	724			
	12/08/77		185.5	8.6	5.0	60	644			
	01/13/78		183.8	8.3	6.5	80	528	A	1	
	02/10/78		179.4	8.2	6.0	80	786	A	1	
	03/15/78		186.3	99.9	11.4	80	1052	A	10	CONSIDERABLE PARTICULATE IN
	04/12/78		181.6	7.8	11.9	80	1010	A	12	GRAY DEBRIS IN WATER
REC COUNT - 7 FOR 54										
54A	06/11/78		203.5	99.9	12.5	132	701	A	15	NEW WELL; PH BELOW PAPER RA
	07/27/78		202.9	8.5	13.0	138	822	A	30	
	08/19/78		202.9	8.4	99.9	130	999999	A	100	SCT OUT,RECOVERY DONE
	09/20/78		203.0	8.4	12.9	130	890	A	20	
	10/13/78		203.2	8.2	12.0	120	819	A		
REC COUNT - 5 FOR 54A										
54B	06/11/78		11.4	99.9	12.9	114	667	A	10	NEW WELL; PH BELOW PAPER RA
	07/28/78		11.6	8.6	12.1	102	736	A	12	
	08/19/78		11.7	8.8	99.9	116	999999	A	31	SCT OUT,RECOVERY DONE
	09/20/78		12.1	8.8	11.0	130	746	A	20	
	10/13/78		12.4	8.2	11.0	124	670	A		
REC COUNT - 5 FOR 54B										
55	10/06/77		42.1	99.9	99.9	9999	999999	Z		PUMP NOT OPERATIONAL

WELL NO.	DATE MM/DD/YY	FLOWING SIGN(-)	WATER LEVEL-FT	PH	TEMP DEG-C	ALKALINT MG/L	CONDUCT MM/CM	SITE STATUS	TIME PUMPED	REMARKS
55	11/09/77		48.1	9.2	6.0	60	535			
	12/08/77		50.8	9.0	6.0	60	448			
	01/13/78		51.3	8.9	10.0	80	355	A	5	
	02/10/78		60.3	8.8	8.0	60	471	A	5	
	03/15/78		55.4	99.9	11.2	100	656	A	10	BELIEVE WELL PUMP 15 MIN PR
	04/12/78		999.9	8.2	11.0	9999	678	Z	10	DEPTH PROBE LOST IN WELL 54
	05/10/78		49.3	6.8	11.1	60	653	Z	10	STREAM 20 YDS AWAY BANK FUL
	06/10/78		50.9	99.9	99.9	9999	999999	A		PUMP DOES NOT OPERATE
	07/27/78		50.1	8.8	12.0	150	1760	A	20	SPECIFIC CAP=0.30GPM/FT
	08/19/78		51.6	8.1	99.9	132	999999	A	16	SCT OUT
	09/20/78		49.8	8.6	11.0	170	760	A	20	
	10/13/78		51.5	8.3	10.2	144	819	A		
REC COUNT - 13 FOR 55										
56	10/07/77		999.9	8.8	11.5	280	844	F		
	11/09/77		999.9	8.6	11.0	320	1160	F		
	12/09/77		999.9	8.6	4.0	240	792	F		
	01/13/78		999.9	8.5	10.0	360	852	F	0	ARTESIAN
	02/10/78	-	15.0	8.8	5.0	340	983	F	5	
	03/14/78	-	9.5	99.9	9.8	320	1256	G		FLOWING ARTESIANS WITHIN 20
	04/09/78	-	10.7	8.5	10.0	300	1207	F		
	05/01/78	-	11.1	8.5	11.4	460	1202	G		NEARBY FLOWING ARTESIAN
	06/06/78	-	13.0	7.6	12.9	486	1151	F		PH BY PAPER
	07/24/78	-	13.7	8.5	12.2	494	1335	F		FLOWING AT 1.87GPM
	08/16/78	-	14.3	8.5	99.9	694	999999	F	30	SCT OUT
	09/27/78	-	14.1	8.3	14.0	520	1165	F		
	10/10/78	-	11.8	8.4	13.0	482	1207	F		
REC COUNT - 13 FOR 56										
57	10/07/77		999.9	8.5	10.0	360	738	F		
	11/09/77		999.9	7.6	12.0	380	1108	F		
	12/08/77		999.9	7.9	8.0	260	1182	F		
	01/13/78		999.9	8.7	10.0	400	781	F	1	ARTESIAN
	02/10/78	-	8.1	8.7	9.0	380	1130	F		CONTINUOUS
	03/14/78	-	13.9	99.9	12.2	300	1202	F		
	04/09/78	-	15.0	8.8	10.8	300	1264	F		
	05/02/78	-	15.7	8.5	14.1	480	1266	F		
	06/06/78	-	14.8	7.6	16.0	540	1219	F		PH BY PAPER
	07/24/78	-	16.2	8.4	14.6	540	3583	F		SEE RECOVERY DATA,BATT,WEAK
	08/16/78	-	19.1	7.4	99.9	530	999999	F	45	SCT OUT
	09/27/78	-	18.9	8.1	16.0	560	1244	F		
	10/10/78	-	15.7	8.2	15.1	516	1298	F		
REC COUNT - 13 FOR 57										
58	10/07/77		83.7	7.5	14.0	400	1294			
REC COUNT - 1 FOR 58										

MONTHLY MONITORING DATA-POWDER RIVER BASIN

REPORT DATE - 78/12/18.

WELL NO.	DATE MM/DD/YY	FLOWING SIGN(-)	WATER LEVEL-FT	PH	TEMP DEG-C	ALKALINT MG/L	CONDUCT MM/CM	SITE STATUS	TIME PUMPED	REMARKS
59	10/07/77		7.3	8.0	14.0	440	841			
	11/17/77		7.3	8.4	9.5	540	1007			
	12/09/77		12.5	8.1	5.0	360	951			
	01/13/78		12.8	8.2	7.0	480	729		1	
	02/10/78		13.2	8.5	5.5	540	772	Z		HAND PUMP
	03/14/78		11.0	99.9	10.0	440	1136			WELL NEXT TO HOUSE WHICH HA
	04/09/78		11.8	8.0	10.0	440	1107	A	5	GRAY COLOR, ORGANIC MATERIA
	05/02/78		11.8	8.0	11.2	600	1140			
	06/05/78		11.9	7.2	11.2	680	1099	A	5	PH BY PAPER
	07/24/78		10.0	8.0	11.0	670	1147	A	3	PUMPED AT 0.95GPM
	08/15/78		11.1	8.0	99.9	644	999999	A	3	SCT OUT,HAND PUMPED
	09/24/78		11.0	8.0	12.0	640	1088	A		
	10/10/78		11.0	7.9	12.0	627	1182	A		10GAL PUMPED

REC COUNT - 13 FOR 59

WELL NO.	DATE MM/DD/YY	FLOWING SIGN(-)	WATER LEVEL-FT	PH	TEMP DEG-C	ALKALINT MG/L	CONDUCT MM/CM	SITE STATUS	TIME PUMPED	REMARKS
6	09/19/77		26.3	7.6	12.5	220	569			
	10/10/77		21.0	7.9	11.0	220	442			
	11/16/77		21.2	7.4	9.5	180	525			
	12/19/77		21.4	7.6	8.5	200	406			
	01/24/78		21.1	8.2	5.0	200	322	A		BOTTLE
	02/22/78		21.4	99.9	7.7	120	386	A		HANDDUG
	03/23/78		20.9	5.6	.7	40	124	A		INFLUX OF SNOW MELT. PH BY
	04/12/78		19.2	6.2	7.0	100	476	A		PH WITH PAPER BAILED SAMPLE
	05/09/78		19.5	7.3	10.5	120	476	A		THIEF SAMPLE
	06/06/78		19.6	7.0	12.0	194	584	A		BAILED
	07/17/78		19.7	7.6	13.0	290	613	A	0	BAILED SAMPLE
	08/16/78		19.8	7.3	11.5	278	542	A		BAILED
	09/30/78		19.6	7.4	12.0	330	476	A		THIEF SAMPLED-SKUNK IN WELL
	10/30/78		19.5	7.6	10.1	310	1062	A		SCT PROBS. BAILED

REC COUNT - 14 FOR 6

WELL NO.	DATE MM/DD/YY	FLOWING SIGN(-)	WATER LEVEL-FT	PH	TEMP DEG-C	ALKALINT MG/L	CONDUCT MM/CM	SITE STATUS	TIME PUMPED	REMARKS
60	10/07/77		999.9	8.9	12.5	100	430	F		
	11/08/77		999.9	9.2	10.0	120	397	F		
	12/09/77		999.9	8.3	8.0	80	419	F		
	01/09/78		999.9	8.8	10.0	140	312	F	1	ARTESIAN
	02/10/78		999.9	7.6	5.0	160	709	F	5	PIPE BROKEN
	03/15/78		999.9	99.9	7.3	100	525	Z		CANNOT PRESSURIZE ARTESIAN

REC COUNT - 6 FOR 60

WELL NO.	DATE MM/DD/YY	FLOWING SIGN(-)	WATER LEVEL-FT	PH	TEMP DEG-C	ALKALINT MG/L	CONDUCT MM/CM	SITE STATUS	TIME PUMPED	REMARKS
61	10/12/77		999.9	8.6	99.9	340	620	F		
	11/08/77		999.9	8.4	13.5	340	666	F		
	12/09/77		999.9	8.1	7.0	240	614	F		
	01/13/78		999.9	8.5	12.0	340	564	F	1	ARTESIAN
	02/10/78	-	27.7	8.5	8.0	340	658	F	5	
	03/15/78	-	30.3	99.9	12.5	340	900	F		
	04/09/78	-	27.0	8.2	13.6	300	783	F		LEAKY GAGE HOOK-UP
	05/10/78	-	24.9	8.1	14.1	340	769	F		PH BY PAPER
	06/06/78	-	24.5	7.4	14.2	482	773	F		PH BY PAPER

WELL NO.	DATE MM/DD/YY	FLOWING SIGN(-)	WATER LEVEL-FT	PH	TEMP DEG-C	ALKALINT MG/L	CONDUCT MM/CM	SITE STATUS	TIME PUMPED	REMARKS
61	07/25/78	-	21.3	8.2	14.9	470	839	F		FLOWING AT 1.33GPM
	08/16/78	-	23.2	8.1	99.9	449	999999	F	20	SCT OUT
	09/24/78	-	19.9	8.1	15.1	520	734	F		
	10/14/78	-	19.9	8.0	14.0	501	738	F		
REC COUNT - 13 FOR 61										
62	10/12/77		999.9	9.1	99.9	120	370	F		
	11/04/77		999.9	8.6	14.0	120	472	F		
	12/05/77		999.9	9.0	8.5	160	310	F		
	01/09/78		999.9	8.9	11.0	140	386	F	0	ARTESIAN
	02/06/78	-	9.2	9.0	9.9	140	384	F		CONTINUOUS
	03/06/78	-	7.5	99.9	9.6	100	528	F		
	04/26/78	-	6.7	8.6	13.4	120	497	F		
	05/12/78	-	4.2	7.2	12.0	120	498	F		PH BY PAPER
	06/11/78	-	6.2	99.9	13.0	176	493	F		PH BELOW PAPER RANGE
	07/28/78	-	6.9	8.9	13.8	174	715	F		FLOWING AT 0.48GPM
	08/21/78	-	7.8	8.9	99.9	182	999999	F	20	SCT OUT
	09/24/78	-	6.9	8.6	13.0	182	770	F		
	10/13/78	-	3.5	8.5	12.5	174	516	F		
REC COUNT - 13 FOR 62										
63	10/12/77		999.9	8.5	99.9	100	390	F		
	11/04/77		999.9	8.1	17.0	120	475	F		
	12/05/77		999.9	8.7	10.0	100	369	F		
	01/09/78		999.9	8.8	11.0	120	366	F	0	ARTESIAN
	02/06/78	-	24.3	9.2	11.3	200	376	F	5	
	03/06/78	-	20.6	99.9	11.9	120	485	F		
	04/26/78	-	21.5	8.7	13.3	120	472	F		
	05/12/78	-	19.3	7.4	13.1	100	491	F		PH BY PAPER
	06/11/78	-	21.3	99.9	13.0	170	473	F		PH BELOW PAPER RANGE
	07/28/78	-	25.4	8.9	13.0	170	495	F		FLOWING AT 4.12GPM
	08/21/78	-	23.9	9.0	99.9	172	999999	F	30	SCT OUT,RECOVERY DONE
	09/24/78	-	23.3	8.6	14.0	240	673	F		
	10/13/78	-	19.9	8.7	12.0	164	490	F		
REC COUNT - 13 FOR 63										
64	03/30/78		14.7	6.9	8.8	400	3015	A		THIEF SAMPLED
	04/25/78		15.7	7.1	9.7	440	3350	A		WATER, CLOUDY GRAY
	05/05/78		15.1	7.0	8.1	480	4151	A		STREAM 20' AWAY.
	06/07/78		14.6	99.9	9.8	498	3184	A		PH BELOW PAPER RANGE
	07/25/78		14.2	7.1	10.5	478	3138	A		
	08/16/78		15.1	7.1	99.9	494	999999	A		BAILED SCT OUT
	09/19/78		16.3	7.1	9.0	520	3822	A		
	10/11/78		15.4	7.2	10.9	520	2979	A		
REC COUNT - 8 FOR 64										
65	03/30/78		56.8	7.2	9.9	340	864	A		

REPORT DATE - 78/12/18.

WELL NO.	DATE MM/DD/YY	FLOWING SIGN(-)	WATER LEVEL-FT	PH	TEMP DEG-C	ALKALINT MG/L	CONDUCT MM/CM	SITE STATUS	TIME PUMPED	REMARKS
65	04/10/78		56.4	7.1	9.4	240	866	A	15	
	05/03/78		53.8	7.0	10.0	360	866	A	10	
	06/07/78		56.6	99.9	11.3	376	849	A	10	PH BELOW PAPER RANGE
	07/25/78		60.3	7.4	10.5	392	966	P		SEE RECOVERY DATA
	08/16/78		54.3	7.4	99.9	564	999999	R	20	SCT OUT
	09/19/78		52.8	7.2	11.2	370	934	A		
	10/11/78		52.6	7.2	12.0	384	927	A		
REC COUNT - 8 FOR 65										
66	03/30/78		48.3	7.2	11.1	200	1632	A		
	04/25/78		48.2	7.2	10.2	180	1568	A	15	
	05/05/78		48.2	7.4	10.2	220	1765	A	20	
	06/06/78		48.3	99.9	13.4	248	1755	A	34	PH BELOW PAPER RANGE
	07/27/78		48.3	7.1	12.5	238	1854	P		SEE RECOVERY DATA
	08/21/78		48.2	7.2	99.9	258	999999	R	8	SCT OUT,RECOVERY DONE
	09/20/78		47.9	7.2	11.1	270	1998	A	20	
	10/12/78		47.9	7.5	10.5	262	1933	A		
REC COUNT - 8 FOR 66										
67	04/25/78		58.8	7.0	12.3	340	2131	A	13	
	05/02/78		59.5	7.1	11.9	400	2600	A	10	
	06/05/78		58.2	99.9	11.2	480	2666	A	15	PH BELOW PAPER RANGE
	07/24/78		57.7	7.3	11.1	484	3335	A	25	POSSIBLE WEAK BATTERIES
	08/15/78		59.3	7.6	99.9	674	999999	A	25	SCT OUT
	09/19/78		61.0	7.2	10.8	480	2723	A	15	
	10/10/78		61.3	7.6	12.0	425	2821	A		
REC COUNT - 7 FOR 67										
67A	05/02/78		55.7	4.1	13.3	0	3439	Z	10	LEVEL TAKEN AFTER PUMP RAN.
	06/06/78		55.6	4.5	13.1	0	3268	A	15	PH BELOW PAPER RANGE
	07/24/78		55.4	4.4	13.5	0	3452	A	10	
	08/15/78		54.6	4.2	99.9	0	999999	A	21	SCT OUT,RECOVERY DONE
	09/19/78		55.1	4.7	12.7	0	3252	A	20	
	10/10/78		55.0	4.4	13.0	0	3524	A		
REC COUNT - 6 FOR 67A										
7	09/20/77		18.5	7.2	15.0	520	2945			
	10/10/77		18.8	7.7	11.0	360	1865			
	11/16/77		17.5	7.6	10.0	400	2556			
	12/19/77		16.4	7.4	8.0	260	2081			
	01/23/78		17.4	8.5	8.0	380	1572	A	1	
	02/21/78		19.0	7.2	10.2	400	2104	A	5	
	03/22/78		16.5	6.8	10.1	360	4646	A	10	PH BY PAPER COLOR INDICATOR
	04/12/78		15.9	6.8	10.0	380	4403	A	5	PH WITH PAPER
	05/09/78		15.0	7.3	12.0	420	3627	A	5	
	06/06/78		15.3	6.6	15.0	537	4697	A	5	
	07/17/78		16.7	7.3	12.0	595	4836	A	05	

WELL NO.	DATE MM/DD/YY	FLOWING SIGN(-)	WATER LEVEL-FT	PH	TEMP DEG-C	ALKALINT MG/L	CONDUCT MM/CM	SITE STATUS	TIME PUMPED	REMARKS
7	08/17/78		17.7	7.3	9.0	578	4668	A		HAND PUMPED 10 GALS
	09/30/78		16.2	7.4	9.9	710	4771	A		PUMPED 20 GALS
	10/30/78		16.5	7.3	9.9	584	4956	A		PUMPED 50 GALS,RUST PARTICU
REC COUNT - 14 FOR 7										
7A	03/22/78		50.9	6.7	9.8	340	3713	A	20	
	04/12/78		49.5	6.7	11.0	360	3593	A	10	
	05/09/78		49.3	7.3	12.0	400	2888	A	10	
	06/06/78		47.9	7.3	15.0	488	3935	A	10	
	07/17/78		48.3	7.3	12.0	564	3896	A	10	
	08/17/78		49.0	7.4	13.0	580	757	A	15	
	09/30/78		48.6	7.5	11.1	550	3610	A	15	
	10/30/78		48.8	7.4	10.1	554	3980	A	20	COLD DAY
REC COUNT - 8 FOR 7A										
70	08/20/78		999.9	99.9	99.9	9999	999999			NO ONE HOME
	09/29/78		9.1	7.6	11.5	460	2180	A	20	
	10/10/78		9.2	7.6	11.5	423	2316	A		
REC COUNT - 3 FOR 70										
71	08/18/78		41.5	8.2	99.9	238	999999	A	29	SCT OUT,RECOVERY DONE
	09/20/78		61.8	7.9	12.0	220	1424	P	20	
	10/12/78		43.7	8.0	11.0	210	2100	A		
REC COUNT - 3 FOR 71										
72	08/19/78		90.7	7.3	99.9	220	999999	P		SCT OUT,RECOVERY DONE
	09/20/78		94.5	7.3	10.5	230	1849	P	30	
	10/13/78		78.8	7.2	10.0	226	1704	A		WATER RUSTY AFTER 20 MIN.
REC COUNT - 3 FOR 72										
73	08/21/78		999.9	8.0	99.9	180	999999	F		SCT OUT,NO A COLLAR YET
	09/20/78		999.9	7.9	11.4	190	605	F		
	10/13/78		999.9	7.9	11.0	178	526	F		NOT ADAPTABLE TO ARTES COLL
REC COUNT - 3 FOR 73										
8	09/20/77		20.0	5.3	16.2	60	1053			
	10/10/77		19.5	8.8	11.5	60	844			
	11/15/77		19.5	5.6	11.0	40	1381			
	12/19/77		19.3	5.6	11.5	60	817			
	01/23/78		19.5	7.6	10.0	60	710	A		BOTTLE
	02/21/78		19.2	99.9	10.5	40	826	A		BOTTLE
	03/22/78		18.2	5.9	10.2	160	1765	A		PH BY PAPER, WATER COLORED
	04/12/78		18.1	5.3	11.0	100	1589	A		PH WITH PAPER ORANGE COLOR
	05/09/78		18.1	5.1	13.0	80	1370	A		THIEF SAMPLE
	06/06/78		17.6	5.4	13.0	96	1762	A		BAILED

```
                              MONTHLY MONITORING DATA-POWDER RIVER BASIN

                                                                                            REPORT DATE -  78/12/18.

  WELL NO.     DATE        FLOWING   WATER      PH    TEMP    ALKALINT   CONDUCT   SITE    TIME                REMARKS
               MM/DD/YY    SIGN(-)   LEVEL-FT         DEG-C   MG/L       MM/CM     STATUS  PUMPED

 8             07/17/78              17.8      5.4   13.0     112       1670      A        0     BAILED SAMPLE
               08/17/78              17.1      5.4   12.0      98       1598      A              BAILED
               09/15/78              18.3      5.8   10.1     250       2096      A       20
               10/27/78              18.2      5.7   10.2     116       1765      A              COLOR DIFFICULTY-BAILED

       REC COUNT -   14 FOR 8

 8A            03/22/78              14.7      6.7    9.3     220       2605      A              WATER COLOR BROWN PH BY PAP
               04/12/78              14.9      6.3    9.8     280       2427      A              PH WITH PAPER, WATER MUDDY
               05/09/78              14.6      6.3   12.0     340       1948      A
               06/06/78              14.4      6.9    9.0     367       2917      A              BAILED
               07/17/78              14.9      7.2   11.8     443       2702      A              BAILED SAMPLE
               08/17/78              15.0      7.2   11.0     383       2694      A              BAILED
               09/15/78              15.1      7.3    8.0     410       2994      A       20
               10/27/78              15.0      7.2   10.9     412       2924      A              BAILED

       REC COUNT -    8 FOR 8A

 9             09/20/77              72.1      7.9   19.1    1080       1748
               10/10/77              73.5      8.0   11.0     600       1381
               11/15/77             999.9     99.9   99.9    9999     999999      Z              PUMP REMOVED
               12/19/77             999.9     99.9   99.9    9999     999999      Z              PUMP REMOVED
               01/23/78             999.9     99.9   99.9    9999     999999      Z              PUMP REMOVED
               02/22/78              65.0     99.9   10.0     760       1363      A       10
               03/22/78              65.9      7.2    9.8     740       2113      A        2     HAND PUMPED, PH BY PAPER
               04/12/78              72.3      6.9   10.5     760       1681      A        5     PH WITH PAPER
               05/09/78              72.4      7.9   12.5     800       1986      A        5
               06/06/78              70.3      7.6   14.0     821       2395      A        5
               07/18/78              66.7      7.2   14.0    1012       2330      A       05
               08/17/78              65.0      7.3   12.0     962       2048      A       15
               09/30/78              63.5      7.6   12.2     900       2070      A       15
               10/30/78              94.5      7.7   11.1     960       2549      R       20     MAYBE RECENTLY PUMPED

       REC COUNT -   14 FOR 9

         RECORD  TOTAL    942
        106 BREAKS FOR WELLNO




RUN DATE   78/12/18.  RUT SECS    17.099
UNITS          NUMBER     CCUS    PERCENT
CPU SEC         2.572   19.523     57.230
CMP UNITS       1.455    7.714     22.613
DISK REQS         456    4.918     14.416
DISK SECT        4517    0.608      1.782
JOB INITIATION           1.350      3.957
JOB PROCESSING CCUS     34.113
```

APPENDIX C - LABORATORY ANALYTICAL PROCEDURES

BORON
(Curcumin Method)

1. Scope and Application
   1.1 This colorimetric method finds maximum utility for waters whose boron content is below 1 mg/l.
   1.2 The optimum range of the method on undiluted or unconcentrated samples is 0.1-1.0 mg/l of boron.
2. Summary of Method
   2.1 When a sample of water containing boron is acidified and evaporated in the presence of curcumin, a red-colored product called rosocyanine is formed. The rosocyanine is taken up in a suitable solvent, and the red color is compared with standards either visually or photometrically.
3. Comments
   3.1 Nitrate nitrogen concentrations above 20 mg/l interfere.
   3.2 Significantly high results are possible when the total of calcium and magnesium hardness exceeds 100 mg/l as $CaCO_3$. Passing the sample through a cation exchange resin eliminates this problem.
   3.3 Close control of such variables as volumes and concentrations of reagents, as well as time and temperature of drying, must be exercised for maximum accuracy.
4. Precision and Accuracy
   4.1 A synthetic sample prepared by the Analytical Reference Service, PHS, containing 240 µg/l b, 40 µg/l As, 250 µg/l Be, 20 µg/l Se, and 6 µg/l V in distilled water, was analyzed by the curcumin method with a relative standard deviation of 22.8% and a relative error of 0% in 30 laboratories.

5. Reference

5.1 The procedure to be used for this determination is found in:
Standard Methods for the Examination of Water and Wastewater, 13th Edition, p 69, Method 107A (1971).

CALCIUM (Ca)

Unit Reported: mg/liter, as Ca.

Measurement: By atomic absorption spectrophotometer using Perkin Elmer Model 603, using a wavelength of 422.7 nm. The instrument is set according to the manufacturer's instructions. The samples are acidified at the time of collection to pH ± 2 with nitric acid. A calibration curve is plotted covering the linear range. Samples containing calcium beyond the linear range are diluted with distilled water. Phosphate and sulfate interfere but are masked by the addition of lanthanum.

Optimum Concentration Range:
0.2-10 mg/l using a wavelength of 422.7 nm

Sensitivity: 0.08 mg/l

Detection Limit: 0.003 mg/l

Preparation of Standard Solution:

1. Stock Solution: Suspend 1.250 g of $CaCO_3$ (analytical reagent grade), dried at 180°C for 1 hour before weighing, in deionized distilled water and dissolve cautiously with a minimum of dilute HCl. Dilute to 1000 ml with dionized distilled water. 1 ml = 0.5 mg Ca (500 mg/l).
2. Lanthanum chloride solution: Dissolve 29 g of La_2O_3, slowly and in small portions in 250 ml conc. HCl (Caution: Reaction is violent) and dilute to 500 ml with deionized distilled water.
3. Prepare dilutions of the stock calcium solutions to be used as calibration standards at the time of analysis. To each calibration

standard solution, add 1.0 ml of $LaCl_3$ solution for each 10 ml of volume of working standard, ie., 20 ml working standard + 2 ml $LaCl_3$ = 22 ml.

Instrumental Parameters (General):

1. Calcium hollow cathode lamp - Perkin Elmer lamp #
2. Wavelength: 422.7 nm
3. Fuel: Acetylene
4. Oxidant: Air
5. Type of flame: Reducing

Precision and Accuracy:

At concentrations 5 mg/l - 100 mg/l, the standard deviations range from ± 0.5 - ± 1.0 respectively. Recoveries at both levels are = 100%.

CHLORIDE DETERMINATION BY ION SPECIFIC ELECTRODES

Equipment:

1. Orion Model 801A digital Ph/mv meter.
2. Orion Model 94-17 Chloride electrode. Reference electrode Orion Model 90-02 double junction reference electrode.
3. Magnetic stirrer.
4. Graph paper - 4 cycle, semi-logarithmic.
5. Polishing strips - Orion Cat. # 94-82-01.

Reagents & Standards:

1. Distilled or deionized water.
2. Ionic strength adjuster - 1 Molar Na NO_2 solution, dissolve 8.5 g of Na NO_2 in 100 ml distilled water.
3. Standard chloride solution. 100 ppm (Weigh 33 mg of Na Cl dissolved in 200 ml distilled water)

100 ppm	100 ml
50 ppm	100 ml
30 ppm	100 ml
20 ppm	100 ml
10 ppm	100 ml
5 ppm	100 ml
2 ppm	100 ml
1 ppm	100 ml
0.5 ppm	100 ml
0.2 ppm	100 ml
0.1 ppm	100 ml

4. Reference electrode filling solutions
   4.1 Inner solution - Orion 40-00-02
   4.2 Outer solution - Orion 40-00-03 (10% NO_3 solution)

Electrodes Assembling and Connecting to Ph meter:

Remove the black rubber protective cap from chloride electrode, insert in the holder clamp, insert the plug to the Ph meter jack.

Fill the inner tank of the reference electrode with the blue solution and the outer part with 10% KNO_3 solution - connect the phone tip connector to the Ph meter. Wash the electrodes with distilled water, blot dry.

Checking Electrodes Operations with 801A Ph/mv Meter:

1. Put 100 ml of 10 ppm Chloride in a beaker, add 2 ml of ionic strength adjuster; turn 801A Function Switch to Mv position. Place electrodes in the solution at ½" depth. Read in MV.
2. Remove the electrodes from the solution, wash with distilled water, blot dry, place them in 100 ml of 100 ppm chloride solution, add 2 ml of ISA, stir, read Mv and record.
3. Find the difference in Mv readings - if the reading's difference is between 53 - 59 Mv, the apparatus functions OK.

Calibration Curve for Low Level Chloride:

1. Rinse electrodes, blot dry.
2. Place electrodes in 10 ppm chloride solution, add 2 ml ISA, stir in solution, set the function switch on the meter to REL. Mv; set the meter reading to 0.00 by pressing the reset button - record the reading.
3. Rinse electrodes, blot dry, and place in 100 ppm standard, add 2 ml ISA, stir, and wait for stable reading and record.

4. Repeat step 3 with 0.1 ppm standard, 0.2 ppm, 0.5 ppm, 1 ppm, 5 ppm, 20 ppm, 30 ppm, and 50 ppm.
5. Plot the millivolt reading (linear axis) against concentration (log axis) on standard 4 cycle Semilog table. The curve as shown in Fig. I should be obtained.
6. Transfer 50/or 100 ml sample into a beaker, add 1 ml/or 2 ml ISA and repeat the step #3.
7. Calculate the concentration of chloride from standard curve.

HARDNESS, Total

1. Scope and Application

   1.1 This method is applicable to drinking, surface, and saline waters, domestic and industrial wastes.

   1.2 The method is suitable for all concentration ranges of hardness; however, in order to avoid large titration volumes, use a sample aliquot containing not more than 25 mg $CaCO_3$.

2. Summary of Method

   2.1 Calcium and magnesium ions in the sample are sequestered upon the addition of disodium ethylenediamine tetraacetate (Na_2EDTA). The end point of the reaction is detected by means of Calmagite Indicator, which has a red color in the presence of calcium and magnesium and a blue color when cations are sequestered.

3. Comments

   3.1 Excessive amounts of heavy metals can interfere. This is usually overcome by complexing the metals with cyanide.

      3.1.1 Routine addition of sodium cyanide solution (Caution: deadly poison) to prevent potential metallic interference is recommended.

4. Precision and Accuracy

   4.1 Forty-three analysts in nineteen laboratories analyzed six synthetic water samples containing exact increments of calcium and magnesium salts, with the following results:

Increment as Total Hardness mg/liter, $CaCO_3$	Precision as Standard Deviation mg/liter, $CaCO_3$	Accuracy as	
		Bias, %	Bias, Mg/liter, $CaCO_3$
31	2.87	-0.87	-0.003
33	2.52	-0.73	-0.24
182	4.87	-0.19	-0.4
194	2.98	-1.04	-2.0
417	9.65	-3.35	-13.0
444	8.73	-3.23	-14.3

(FWPCA Method Study 1, Mineral and Physical Analyses)

4.2 In a single laboratory (MDQARL), using surface water samples at an average concentration of 194 mg $CaCO_3$/1, the standard deviation was ± 3.

5. References

5.1 The procedure to be used for this determination is found in:

Standard Methods for the Examination of Water and Wastewater, 13th Edition, p 179, Method 122B (1971).

ASTM Standards, Part 23, Water; Atmospheric Analysis, p 168, Method D1126-67 (1973).

IRON (Fe)

Unit Reported: mg/liter, as Fe.

Measurement: By A. A. spectrophotometric method using Perkin Elmer Model 603, applying wavelength of 248.3 nm. Set up the instrument according to the manufacturer's instructions. Samples are acidified to pH ± 2 with nitric acid at the time of collection. A calibration curve is plotted covering the linear range (ie., 0.1 mg/l - 10 mg/l). Samples containing iron beyond the linear range are diluted with distilled water. Samples containing iron below sensitivity limit are concentrated on evaporation in acid solution.

Optimum Concentration Range: 0.3-10 mg/l using a wavelength of 248.3 nm

Sensitivity: 0.12 mg/l

Detection Limit: 0.02 mg/l

Preparation of Standard Solution:

1. Stock Solution: Carefully weigh 1.000 g of pure iron wire (analytical reagent grade) and dissolve in 5 ml redistilled HNO_3, warming if necessary. When solution is complete make up to 1 liter with deionized distilled water. 1 ml = 1 mg Fe (1000 mg/l): Use commercial stock solution.
2. Prepare dilutions of the stock solution to be used as calibration standards at the time of analysis. The calibration standards should be prepared using the same type of acid (HCl or HNO_3) and at the same

concentration as the samples for analysis.

Sample Preparation:

1. The procedure for the determination of total metals as given in Hittman Analytical Lab Procedure has been found to be satisfactory.

Instrumental Parameters (General)

1. Iron Hollow cathode lamp
2. Wavelength: 248.3 nm, slit sitting 3(0.2 nm)
3. Fuel: Acetylene
4. Oxidant: Air
5. Type of flame: Oxidizing (lean, blue)

Precision and Accuracy:

At concentration ranges from 0.12 mg/l to 10 mg/l, the standard deviation varies from ± 20% - ± 5%.

MAGNESIUM (Mg)

Unit Reported: mg/liter, as Mg. Magnesium contributes to hardness. It is not considered toxic but considered for taste in drinking water.

Measurement: The AA Spectrophotometric Method is used. Perkin Elmer Model 603, using wave length 285.2 nm is set according to the manufacturer instructions. The samples are acidified at the time of collection to pH ≤ 2 at the time of collection. A calibration curve is plotted covering the linear range. Samples containing Mg beyond the linear range, are diluted with distilled water.

Optimum Concentration Range:

0.02-2 mg/l using a wavelength of 285.2 nm

Sensitivity: 0.007 mg/l

Detection Limit: 0.0005 mg/l

Preparation of Standard Solution:

1. Stock Solution: Dissolve 0.829 g of magnesium oxide, MgO (analytical reagent grade), in 10 ml of redistilled HNO_3 and dilute to 1 liter with deionized distilled water. 1 ml = 0.50 mg Mg (500 mg/l).
2. Lanthanum chloride solution: Dissolve 29 g of La_2O_3, slowly and in small portions in 250 ml conc. HCl, (Caution: Reaction is violent) and dilute to 500 ml with deionized distilled water.
3. Prepare dilutions of the stock magnesium solution to be used as calibration standards at the time of analysis. To each calibration standard solution, add 1.0 ml of $LaCl_3$

HITTMAN

solution for each 10 ml of volume of working standard, ie., 20 ml working standard + 2 ml $LaCl_3$=22ml.

Instrumental Parameters (General):

1. Magnesium hollow cathode lamp
2. Wavelength: 285.2 nm
3. Fuel: Acetylene
4. Oxidant: Air
5. Type of flame: Reducing

Notes:

1. Analytical sensitivity decreases with increased lamp current.
2. The interference caused by aluminum at concentrations greater than 2 mg/1 is masked by addition of lanthanum. Sodium, potassium and calcium cause no interference at concentrations less than 400 mg/1.
3. Because of the spectral intensity of the 285.2 nm line, the P.M. tube may become saturated. If this situation occurs, the current should be decreased.
4. The following line may also be used: 202.5 nm Relative Sensitivity 25
5. To cover the range of magnesium values normally observed in surface waters (0.1-20 mg/1), it is suggested that the burner be rotated 55°.

Precision and Accuracy:

At concentration ranges of 0.2 mg/liter - 10 mg/liter, the relative standard deviations are between ± 3% - ± 10%. Recoveries at both levels are 100%.

POTASSIUM (K)

Unit Reported: mg/liter, as K.

Measurement: The A. A. spectrophotometric method is used. Perkin Elmer Model 603 using a wavelength of 766.5 nm is set according to the manufacturer's instructions. The samples are acidified to pH ± 2 with nitric acid at the time of collection. A calibration curve is plotted covering the linear range. Samples containing potassium beyond the linear range are diluted with distilled water.

Optimum Concentration Range:
0.1-2 mg/l using a wavelength of 866.5 nm

Sensitivity: 0.04 mg/l

Detection Limit: 0.005 mg/l

Preparation of Standard Solution:

1. Stock Solution: Dissolve 0.1907 g of KCl (analytical reagent grade), dried at 110°C, in deionized distilled water and make up to 1 liter. 1 ml = 0.10 mg K (100 mg/l).
2. Prepare dilutions of the stock solution to be used as calibration standards at the time of analysis.

Instrumental Parameters (General):

1. Potassium hollow cathode lamp or no lamp in flame emission mode.
2. Wavelength: 766.5 nm
3. Fuel: Acetylene
4. Oxidant: Air
5. Type of flame: Slightly oxidizing

Notes:

1. Potassium absorption is enhanced in the presence of Na, Li and Cs, especially in a high-temperature flame. This enhancement effect of sodium can be eliminated by changing the burner height and the type of flame used. The burner assembly is set approximately 0.05 cm below the optical light path so that the optical light path is sliced at the bottom by the burner head. A fuel-rich flame is used.
2. The 404.4 nm line may also be used. This line has a sensitivity of 5 mg/l for 1% absorption.
3. To cover the range of potassium values normally observed in surface waters (0.0-20/mg/l), it is suggested that the burner be rotated 75°.

Precision and Accuracy:

At 1 mg/l - 10 mg/l the relative standard deviation is ± 10%. Recovery at these levels are = 100%

SODIUM (Na)

Unit Reported: mg/liter, as Na.

Measurement: By atomic absorption spectrophotometer using Perkin Elmer Model 603 in Flame Emission mode at 589.6 nm with air-acetylene flame. The instrument is set according to the manufacturer's instructions. The samples are acidified at the time of collection to pH = 2 with nitric acid. A calibration curve is plotted covering the linear range. Samples containing sodium beyond the linear range are diluted with distilled water.

The concentrations of sodium in the samples are calculated from the calibration curve and with appropriate dilution factor, concentrations are reported in mg/l as Na.

Optimum Concentration Range:

0.03-1.0 mg/l using a wavelength of 589.6 nm

Sensitivity: 0.015 mg/l

Detection Limit: 0.002 mg/l

Preparation of Standard Solutions:

1. Stock Solution: Dissolve 2.542 g of NaCl (analytical reagent grade), dried at 140°C, in deionized distilled water and make up to 1 liter. 1 ml = 1 mg Na (1000 mg/l).
2. Prepare dilutions of the stock solution to be used as calibration standards at the time of analysis.

Instrumental Parameters (General):

1. Sodium hollow cathode lamp or no lamp in case of flame emission.

2. Wavelength: 589.6 nm
3. Fuel: Acetylene
4. Oxident: Air
5. Type of flame: Oxidizing

Precision and Accuracy:

Standard deviations at levels 5 mg/liter - 100 mg/liter should exceed more than ± 1%. Recoveries at these levels are approximately 100%

NITRATE-NITROGEN DETERMINATION BY ION-SELECTIVE ELECTRODES

Principle: The nitrate ion electrode is a selective sensor that develops a potential across a thin, porous, inert membrane that holds in place a water-immersible liquid ion exchanger. The electrode responds only to ionized nitrate ion activity.

Equipment:

1. Nitrate specific Electrode-Orion-Model 93-07.
2. Ph/mv meter. Orion Model 801A.
3. Reference Electrode Orion Model 90-02 double junction.
4. Magnetic Stirrer.
5. Graphic paper - 4 cycle semilog.

Reagents:

1. Distilled or deionized water.
2. Ionic strength adjuster (ISA) o.4m. ammonium sulfate, dissolve 5.3g of reagent grade ammonium sulfate in 100 ml distilled water.
3. Inner filling solution - Orion cat. #900002.
4. Outer filling solution - 0.04m ammonium sulfate solution. Dilute 1 ml of 0.4m ISA to 10 ml and with distilled water.

Nitrate-N Standards:

1. 1000 ppm NO_3^-N solution: Weigh 72.18 mg of anhydrous potassium nitrate (KNO_3), dissolve in 100 ml of distilled water.
2. Calibration standards:
   1. 50 ppm: 5 ml of #1 to 100 ml.
   2. 20 ppm: 2 ml of #1 to 100 ml.
   3. 10 ppm: 1 ml of #1 to 100 ml.
   4. 5 ppm: 0.5 ml of #1 to 100 ml.
   5. 1 ppm: 0.1 ml of #1 to 100 ml.

6. 0.5 ppm: 0.05 ml of #1 to 100 ml.
7. 0.1 ppm: 0.01 ml of #1 to 100 ml.

Electrodes Assembly, Filling:

1. Screw the sensing module through rubber washer to electrode body, remove the black cap from the top of the sensor, connect to a Ph/mv meter.
2. Fill up the inner chamber of the reference electrode with the inner filling solution and outer chamber with outer filling solution, connect the electrode phone-tip to the Ph/mv meter.
3. Place the electrodes in the holder at equal height.

Checking Electrodes Operation:

1. Wash the electrodes with distilled water, blot dry, place the electrodes to about 1" in 100 ml 5 ppm Nitrate-N solution, add 2 ml of ISA, stir, turn functions switch to MV position. Read electrode potential in millivolts and record. X
2. Repeat step #1 using 100 ml of 50 ppm Nitrate-N solution. Read electrode potential in millivolts and record. 1
3. Calculate the difference of potentials if 56 = 1 ml, apparatus is working.

Low Level Nitrate-N Measurement:

A. Calibration Curve:
    1. Rinse electrodes, blot dry, place electrodes in 1 ppm Nitrate-N standard, add 2 ml of ISA, stir. Set the function switch on the meter

to REL. MV. Set the meter reading to 000.0 by pressing the restandardization button on the 801A.

2. Repeat Step #1 using 50 ppm Nitrate-N solution, 0.1 ppm nitrate, 20 ppm, 10 ppm, 5 ppm, 0.5 ppm.
3. Plot the millivolt readings (linear axis) against concentration (log axis) on 4 cycle standard semilog paper. (Fig. 1)

Nitrate-N in Unknown Samples:

1. Transfer 50/100 ml water sample to a beaker, add ½ ml ISA, stir, place electrodes into a depth of 1" after rinsing and blotting. Record the readings in millivolts. Calculate the concentration from the calibration curve direct in ppm.

ORGANIC CARBON
(Total and Dissolved)

1. Scope and Application
   1.1 This method includes the measurement of organic carbon in drinking, surface, and saline waters, domestic and industrial wastes. Exclusions are noted under Definitions and Interferences.
   1.2 The method is most applicable to measurement of organic carbon above 1 mg/l.
2. Summary of Method
   2.1 Organic carbon in a sample is converted to carbon dioxide (CO_2) by wet chemical oxidation. The CO_2 formed can be measured directly by an infrared detector. The amount of CO_2 is directly proportional to the concentration of carbonaceous material in the sample.
3. Definitions
   3.1 The carbonaceous analyzer measures all of the carbon in a sample. Because of various properties of carbon-containing compounds in liquid samples, preliminary treatment of the sample prior to analysis dictates the definition of the carbon as it is measured. Forms of carbon that are measured by the method are:
      A) soluble, nonvolatile organic carbon; for instance, natural sugars.
      B) soluble, volatile organic carbon; for instance, mercaptans.
      C) insoluble, partially volatile carbon; for instance, oils.
      D) insoluble, particulate carbonaceous materials, for instance, cellulose fibers.

E) soluble or insoluble carbonaceous materials adsorbed or entrapped on insoluble inorganic suspended matter; for instance, oily matter adsorbed on silt particles.

4. Sample Handling and Preservation

4.1 Sampling and storage of samples in glass bottles is preferable. Sampling and storage in plastic bottles such as conventional polyethylene and cubitainers is permissible if it is established that the containers do not contribute contaminating organics to the samples.

NOTE 1: A brief study performed in the EPA Laboratory indicated that distilled water stored in new, one quart cubitainers did not show any increase in organic carbon after two weeks exposure.

4.2 Because of the possibility of oxidation or bacterial decomposition of some components of aqueous samples, the lapse of time between collection of samples and start of analysis should be kept to a minimum. Also, samples should be kept cool (4°C) and protected from sunlight and atmospheric oxygen.

4.3 In instances where anlysis cannot be performed within two hours (2 hours) from time of sampling, it is recommended that the sample is acidified ($pH \leq 2$) with HCl or H_2SO_4.

5. Interferences

5.1 Carbonate and bicarbonate carbon represent an interference under the terms of this test and must be removed or accounted for in the final calculation.

5.2 This procedure is applicable only to homogeneous samples which can be injected into the appratus reproducibly by means of a microliter type syringe or pipette. The openings of the syringe or pipette limit the maximum size of particles which may be included in the sample.

6. Apparatus

6.1 Apparatus for blending or homogenizing samples: Generally, a Waring-type blender is satisfactory.

6.2 Apparatus for total and dissolved organic carbon:

6.2.1 A number of companies manufacture systems for measuring carbonaceous material in liquid samples. Considerations should be made as to the types of samples to be analyzed, the expected concentration range, and forms of carbon to be measured.

6.2.2 Oceanography International Total Carbon Analyzer.

7. Reagents

7.1 Distilled water used in preparation of standards and for dilution of samples should be ultra pure to reduce the size of the blank. Carbon dioxide-free, double distilled water is recommended. Ion exchanged waters are not recommended because of the possibilities of contamination with organic materials from the resins.

7.2 Potassium hydrogen phthalate, stock solution, 1000 mg carbon/liter: Dissolve 0.2128 g of potassium hydrogen phthalate (Primary Standard Grade) in distilled water and dilute to 100.0 ml.

NOTE 2: Sodium oxalate and acetic acid are not recommended as stock solutions.

7.3 Potassium hydrogen phthalate, standard solutions: Prepare standard solutions from the stock solution by dilution with distilled water.

7.4 Carbonate-bicarbonate, stock solution, 1000 mg carbon/liter: Weigh 0.3500 g of sodium bicarbonate and 0.4418 g of sodium carbonate and transfer both to the same 100 ml volumetric flask. Dissolve with distilled water.

7.5 Carbonate-bicarbonate, standard solution: Prepare a series of standards similar to step 7.3.
NOTE: This standard is not required by some instruments.

7.6 Blank solution: Use the same distilled water (or similar quality water) used for the preparation of the standard solutions.

8. Procedure

8.1 Follow instrument manufacturer's instructions for calibration, procedure, and calculations.

8.2 For calibration of the instrument, it is recommended that a series of standards encompassing the expected concentration range of the samples be used.

9. Precision and Accuracy

9.1 Twenty-eight analysts in twenty-one laboratories analyzed distilled water solutions containing exact increments of oxidizable organic compounds, with the following results:

Increment as TOC mg/liter	Precision as Standard Deviation TOC, mg/liter	Accuracy as	
		Bias, %	Bias, mg/liter
4.9	3.93	+15.27	+0.75
107	8.32	+ 1.01	+1.08

SULFATE

(Turbidimetric)

1. Scope and Application
   1.1 This method is applicable to drinking and surface waters, domestic and industrial wastes.
   1.2 The method is suitable for all concentration ranges of sulfate; however, in order to obtain reliable readings, use a sample aliquot containing not more than 40 mg SO_4/1.
2. Summary of Method
   2.1 Sulfate ion is converted to a barium sulfate suspension under controlled conditions. The resulting turbidity is determined by a colorimeter or spectrophotometer and compared to a curve prepared from standard sulfate solutions.
   2.2 Suspended matter and color interfere. Correct by running blanks from which the barium chloride has been omitted.
3. Comments
   3.1 Proprietary reagents, such as Hach Sulfaver or equivalent, are acceptable.
4. Precision and Accuracy
   4.1 Thirty-four analysts in 16 laboratories analyzed six synthetic water samples containing exact increments of inorganic sulfate with the following results:

Increment as Sulfate mg/liter	Precision as Standard Deviation mg/liter	Accuracy as	
		Bias, %	Bias, mg/liter
8.6	2.30	-3.72	-0.3
9.2	1.78	-8.26	-0.8
110	7.86	-3.01	-3.3
122	7.50	-3.37	-4.1
188	9.58	+0.04	+0.1
199	11.8	-1.70	-3.4

5. Reference

5.1 The procedure to be used for this determination is found in: Standard Methods for the Examination of Water and Wastewater, 13th Edition, p. 344, Method 156C (1971)

THORIUM

1. Scope and Application
   1.1 This method covers a colorimetric determination of microgram amounts of thorium in water and wastewater. It is sensitive to less than 10^{-9} g of thorium in 1 g of water
   1.2 If particulate matter is present in the samples it can be removed by filtration, treated separately by dissolution procedures, and prepared for the colorimetric method of determination. Interferances from organic compounds that complex thorium are minimized or eliminated by oxidation procedures employing nitric and perchloric acids.
2. Summary of Method
   2.1 Particulate matter in the sample is separated by filtration, dissolved in strong oxidizing acids, and the resulting solutions combined with the filtrate. The thorium in the combined solution is coprecipitated with calcium in the form of oxalate salts. These salts are filtered, dissolved in hydrochloric acid, and the thorium determined spectrophotometrically by the use of 1 - (o-arsonophenylazo) - 2 - napthol - 3, 6 - disulfonic acid as the colorimetric reagent. The characteristic wavelength is 545 nm.
3. Precision and Accuracy
   3.1 The precision of this method is stated in ASTM D2333 as

$$S = 0.137\ x$$

where

S = single operator precision
x = thorium concentration

3.2 The accuracy of this method has been tested with spiked samples. Four samples of groundwater from the Powder River Basin were spiked with 50 micrograms/l. Recoveries ranged from 104 to 130 percent with an average recovery of 120 percent.

4. References

4.1 The procedure to be used for this determination is found in:
ASTM Standards, Part 31, 1978, Method D2333, p. 508-511.

```
                                      WATER QUALITY DATA FROM  WELLS IN POWDER RIVER BASIN
                                                                                                                  REPORT DATE -  78/12/18.

   WELL NO.        DATE          NA         CA         MG          K        SULFATE     BICARB        CL         TDS
                   COLLECT       MG/L       MG/L       MG/L        MG/L     MG/L        MG/L          MG/L       MG/L

1                  01/24/78      200.0      30.0       29.0        45.0     161.0       409.9         9.8        684
                   05/08/78      182.0       8.4       25.7         4.2     246.0       99999.9       9.0        548
                   09/15/78       99.0      15.6       15.5         8.0      80.0       280.6        14.0        450

      REC COUNT -    3 FOR 1

10                 05/09/78      616.0      44.8      118.1        13.1      12.2       99999.9      50.0        2352

      REC COUNT -    1 FOR 10

105A               09/20/78      249.0      35.0       15.0         7.4      55.0       719.8        40.0        617

      REC COUNT -    1 FOR 105A

105B               09/20/78      292.0      56.0       20.0         9.0     99999.9     683.2       9999.9       9999999

      REC COUNT -    1 FOR 105B

105C               09/20/78      196.0      18.5       14.3        11.4      89.0       549.0        30.0        611

      REC COUNT -    1 FOR 105C

11                 01/25/78      100.0     102.0      124.0        15.0     745.2       182.0        10.5        1376
                   05/10/78      118.0      44.4      119.4        13.7     736.0       99999.9      22.0        1260
                   09/15/78       99.0     124.0      109.8        14.0     740.0       183.0        30.0        1307

      REC COUNT -    3 FOR 11

12                 01/25/78      620.0      64.0       46.0        12.4     727.0       919.9         4.2        2008
                   05/10/78      645.0      20.0       25.7        11.6     717.0       99999.9       8.2        2050
                   09/15/78      500.0      71.0       44.0        11.0     731.0       1220.0       11.0        2154

      REC COUNT -    3 FOR 12

13                 01/25/78      690.0       8.0        3.0         4.9     679.0       134.2        23.0        1832
                   05/10/78      674.0       2.8        2.6         1.6     663.0       99999.9      37.0        1749
                   09/15/78      618.0       4.1        2.3         1.0     704.0       1012.6       51.0        1944

      REC COUNT -    3 FOR 13

14                 01/25/78       80.0      83.0       75.0        12.0     345.0       444.1         8.0        856
                   05/10/78       95.8      62.1       97.5         6.5     393.0       99999.9      18.0        992
                   09/15/78       76.0     124.3       66.9         7.0     443.0       671.0        18.0        991

      REC COUNT -    3 FOR 14

15                 01/24/78      180.0       3.0         .6         2.5     155.0       302.6         5.0        554
                   05/10/78      187.0       1.2         .7          .8     123.0       99999.9      11.0        500
                   09/27/78      187.0        .7         .4         1.0     107.0       99999.9      15.0        393

      REC COUNT -    3 FOR 15
```

```
                 WATER QUALITY DATA FROM  WELLS IN POWDER RIVER BASIN

                                                                              REPORT DATE -  78/12/18.
      WELL NO.     DATE        NA      CA       MG       K      SULFATE    BICARB     CL      TDS
                   COLLECT     MG/L    MG/L     MG/L     MG/L   MG/L       MG/L       MG/L    MG/L
 16
                 01/25/78     220.0     2.0       .4     4.5    266.0      244.0      3.3     620
                 05/10/78     231.0     1.3       .4     1.0    196.0    99999.9      8.5     610
                 09/15/78     193.0     1.2       .4     1.0    190.0    99999.9      6.0     709
       REC COUNT -    3 FOR 16
 17
                 01/23/78     190.0     3.0      1.0     5.7      2.0      407.5     45.0     490
                 05/10/78     341.0   250.0    164.0    12.2   1148.0    99999.9    158.0    2470
                 09/15/78     241.0   286.4    162.0    16.0   1315.0      500.2    170.0    2411
       REC COUNT -    3 FOR 17
 18
                 01/26/78     550.0     4.0      9.7     9.0    595.0      729.6      6.3    1426
                 05/10/78     544.0     4.5     17.1     8.3    789.0    99999.9     10.0    1488
                 09/27/78     530.0     9.0     14.5     9.3    519.0    99999.9     22.0    1460
       REC COUNT -    3 FOR 18
 19A
                 01/26/78     450.0    53.0     89.0     9.9    700.0      749.1      5.0    1690
                 05/11/78     474.0   115.0     10.8     9.9    681.0    99999.9     11.0    1988
                 09/15/78     408.0    80.0     86.0    10.0    827.0      915.0     11.0    1773
       REC COUNT -    3 FOR 19A
 19B
                 01/26/78     760.0    16.0      9.2     6.4    846.0      749.1      6.3    1972
                 05/11/78     707.0     8.0    110.7     6.2    861.0    99999.9     10.5    1884
                 09/15/78     698.0    12.0      9.8     8.0    949.0     1049.2     13.0    2222
       REC COUNT -    3 FOR 19B
 19C
                 01/26/78     790.0    37.0     27.0     8.5    685.0      663.7      6.2    2024
                 05/11/78     117.9    14.6     27.1     5.1   1005.0    99999.9     14.5    2360
                 09/15/78     689.0    48.3     28.0     8.0   1088.0     1037.0     15.0    2338
       REC COUNT -    3 FOR 19C
 19D
                 01/26/78     510.0    10.0     60.0    11.5    685.0      675.9      5.2    1992
                 05/11/78     525.0     5.3     28.0     9.5    609.0    99999.9     18.0    1812
                 09/15/78     518.0    35.0     37.3     8.0    792.0      976.0      7.0    1638
       REC COUNT -    3 FOR 19D
 19E
                 01/26/78     640.0    13.0      7.7     9.9    715.0      722.2      6.4    1986
                 05/11/78       5.4    19.8     73.6     7.9    609.0    99999.9     13.0    1646
                 09/15/78     445.0    64.0     72.2    12.0    775.0      915.0      9.5    1774
       REC COUNT -    3 FOR 19E
 2
                 05/08/78     341.0     5.7     10.4     1.5    320.0    99999.9     10.9     982
                 09/30/78     330.0    11.6     10.1     2.2    390.0      658.8     20.0     942
```

```
                                                                                      REPORT DATE -  78/12/18.

                                                                                                             TDS
     WELL NO.          DATE          NA         CA         MG          K        SULFATE     BICARB      CL      MG/L
                       COLLECT       MG/L       MG/L       MG/L        MG/L     MG/L        MG/L        MG/L

 20                    01/26/78      400.0      120.0      214.0       20.0     1360.0       602.7      15.0    2314
                       05/11/78      390.0      126.0      204.0       15.7     1077.0     99999.9     126.0    2054
                       09/31/78      435.0      158.0      207.0       20.0     1220.0     99999.9      37.0    2793

           REC COUNT -   3 FOR 20

 21                    01/23/78      430.0        2.0         .7        3.8       20.7       253.0       5.1     974

           REC COUNT -   1 FOR 21

 22                    01/26/78     1460.0       14.7       12.9       15.4    99999.9      1634.8        .0    1928
                       05/25/78      149.3       17.0       15.2       12.9     2132.0     99999.9      31.0    4096
                       09/29/78     1427.0       43.0       16.7       11.0     1550.0      2074.0      40.0    4327

           REC COUNT -   3 FOR 22

 22A                   05/25/78      950.0       14.2       12.1        7.4      797.0     99999.9      79.0    3668
                       09/29/78      706.0       25.5        9.8        6.7      656.0      1122.4      31.0    2016

           REC COUNT -   2 FOR 22A

 23                    01/26/78       60.0       47.0       90.0       10.0      230.0       505.1       2.4     742
                       05/10/78       67.0       49.7       98.0       11.6      124.0     99999.9       5.0     646
                       09/29/78       73.0       47.0       85.0       10.2      170.0       585.6       9.9     733

           REC COUNT -   3 FOR 23

 24                    02/06/78      687.5        2.6        1.1        2.6     1074.0       280.6      28.0    1799
                       05/02/78      763.0        2.1        1.3        2.9      900.0     99999.9      37.0    1866
                       09/15/78      560.0        2.7         .9        1.5      967.0     99999.9      65.0    1740

           REC COUNT -   3 FOR 24

 251A                  05/25/78      503.0       58.0       61.3        9.9     1375.0     99999.9      18.0    2456
                       09/06/78      708.0       73.5       42.7       12.0     1572.0       414.8      15.5    2440

           REC COUNT -   2 FOR 251A

 251B                  05/25/78      423.0       80.0       75.0        9.9      988.0     99999.9       9.8    2125
                       09/06/78      516.0       81.5       71.0        6.5     1206.0       512.4       8.4    2040

           REC COUNT -   2 FOR 251B

 2514A                 05/25/78      698.0       43.3      154.3       10.9      730.0     99999.9       9.8    2165

           REC COUNT -   1 FOR 2514A

 2514AC                05/25/78      124.0       96.1      122.0       11.3      972.0     99999.9      19.0    1926

           REC COUNT -   1 FOR 2514AC
```

```
                                                                                      REPORT DATE -  78/12/18.
    WELL NO.          DATE          NA          CA          MG          K          SULFATE     BICARB        CL         TDS
                      COLLECT       MG/L        MG/L        MG/L        MG/L       MG/L        MG/L          MG/L       MG/L
2514B                 05/25/78      84.8        12.6        18.5        12.3       1087.0      99999.9       10.5       2960
        REC COUNT -    1 FOR 2514B
252A                  09/06/78      85.0        161.0       205.0       52.0       739.0       756.4         14.0       1597
        REC COUNT -    1 FOR 252A
252B                  09/06/78      93.0        145.0       208.0       7.0        821.0       683.2         22.0       1695
        REC COUNT -    1 FOR 252B
252C                  05/25/78      576.0       5.7         7.1         7.0        456.0       99999.9       64.8       1398
                      09/06/78      516.0       40.0        45.0        5.0        912.0       561.2         13.0       1596
        REC COUNT -    2 FOR 252C
253A                  05/25/78      588.0       3.5         4.5         3.7        99.0        99999.9       9.0        700
                      09/06/78      407.0       12.0        4.0         6.0        619.0       475.8         15.0       1221
        REC COUNT -    2 FOR 253A
253B                  05/25/78      452.0       4.6         4.9         3.6        456.0       99999.9       9.0        1302
                      09/06/78      432.0       8.1         2.5         4.0        711.0       341.6         10.0       1916
        REC COUNT -    2 FOR 253B
253C                  05/25/78      50.2        7.3         6.2         6.2        542.0       99999.9       9.8        1242
                      09/06/78      278.0       4.0         1.3         6.0        125.0       585.6         20.0       1768
        REC COUNT -    2 FOR 253C
254A                  09/06/78      46.0        81.5        92.0        5.5        107.0       646.6         7.5        662
        REC COUNT -    1 FOR 254A
254B                  09/06/78      54.0        81.5        100.0       5.4        125.0       683.2         7.2        675
        REC COUNT -    1 FOR 254B
254C                  09/06/78      478.0       16.5        8.0         4.0        785.0       341.6         9.4        1487
        REC COUNT -    1 FOR 254C
255A                  05/25/78      23.1        76.8        36.2        4.2        83.0        99999.9       9.4        6200
                      09/06/78      14.0        81.5        107.0       5.0        180.0       597.8         8.0        796
        REC COUNT -    2 FOR 255A
255B                  05/25/78      23.1        16.4        12.3        5.1        120.0       99999.9       11.5       668
                      09/06/78      508.0       23.0        10.0        5.0        125.0       488.0         7.0        617
```

WELL NO.	DATE COLLECT	NA MG/L	CA MG/L	MG MG/L	K MG/L	SULFATE MG/L	BICARB MG/L	CL MG/L	TDS MG/L
REC COUNT - 2 FOR 255B									
255C	05/25/78	373.4	26.0	48.1	7.8	913.0	99999.9	14.0	1660
	09/06/78	220.0	49.0	26.4	7.0	931.0	341.6	12.0	1607
REC COUNT - 2 FOR 255C									
256A	09/06/78	133.0	21.0	.2	21.0	89.0	99999.9	15.0	432
REC COUNT - 1 FOR 256A									
256B	09/06/78	48.0	89.0	172.0	8.0	271.0	915.0	13.0	1125
REC COUNT - 1 FOR 256B									
256C	09/06/78	54.0	82.5	116.4	16.0	235.0	671.0	16.0	848
REC COUNT - 1 FOR 256C									
256D	09/06/78	32.0	20.0	1.2	13.5	107.0	99999.9	7.2	212
REC COUNT - 1 FOR 256D									
256E	09/06/78	38.0	27.0	44.0	9.0	125.0	256.2	7.5	357
REC COUNT - 1 FOR 256E									
256F	09/06/78	18.0	65.6	67.1	4.0	107.0	439.2	7.6	498
REC COUNT - 1 FOR 256F									
258A	05/25/78	123.8	67.4	94.7	16.3	449.0	99999.9	14.5	4300
	09/06/78	121.0	81.5	81.0	13.5	418.0	414.8	26.0	923
REC COUNT - 2 FOR 258A									
258B	05/25/78	260.2	20.4	3.1	22.4	352.0	99999.9	48.0	988
	09/06/78	304.0	42.0	.8	19.0	382.0	99999.9	46.0	1051
REC COUNT - 2 FOR 258B									
258C	05/25/78	191.1	86.9	122.7	5.5	198.0	99999.9	3.5	1700
	09/06/78	18.0	225.5	118.0	13.0	272.0	610.0	5.8	930
REC COUNT - 2 FOR 258C									
26	05/09/78	284.0	.8	.5	10.5	88.0	99999.9	41.0	556
	09/15/78	269.0	.7	.2	.7	77.0	99999.9	54.0	655
REC COUNT - 2 FOR 26									

WATER QUALITY DATA FROM WELLS IN POWDER RIVER BASIN

REPORT DATE - 78/12/18.

WELL NO.	DATE COLLECT	NA MG/L	CA MG/L	MG MG/L	K MG/L	SULFATE MG/L	BICARB MG/L	CL MG/L	TDS MG/L
27A	09/15/78	657.0	4.9	5.6	4.5	809.0	99999.9	9.0	1840
REC COUNT - 1 FOR 27A									
28A	05/10/78	327.0	9.0	8.1	7.0	753.0	99999.9	7.5	1544
	09/27/78	502.0	24.1	7.7	4.0	780.0	439.2	11.5	1351
REC COUNT - 2 FOR 28A									
28B	05/10/78	226.0	.8	.0	.5	62.0	99999.9	18.0	496
	09/15/78	220.0	.5	.1	.5	59.0	99999.9	14.0	448
REC COUNT - 2 FOR 28B									
29	05/11/78	573.0	1.8	1.1	4.0	.0	99999.9	48.0	496
	09/31/78	534.0	3.0	1.3	3.1	.0	1439.6	64.0	1151
REC COUNT - 2 FOR 29									
3	01/24/78	620.0	13.0	135.0	33.0	1485.0	419.7	23.0	2420
	05/08/78	644.0	13.6	131.9	13.0	1359.0	99999.9	21.0	2360
	09/15/78	557.0	167.0	219.0	14.0	1838.0	841.8	150.0	3354
REC COUNT - 3 FOR 3									
30	09/15/78	454.0	67.5	66.5	9.0	949.0	585.6	17.0	1609
REC COUNT - 1 FOR 30									
4	01/24/78	850.0	142.0	230.0	60.0	2500.0	766.2	32.0	3728
	05/08/78	861.0	148.0	230.0	13.4	2155.0	99999.9	31.0	3738
	09/30/78	512.0	150.0	204.0	12.5	1700.0	988.2	56.0	3979
REC COUNT - 3 FOR 4									
40	01/10/78	42.8	17.9	7.6	9.7	84.6	226.9	3.6	1141
	05/12/78	76.0	20.3	9.0	5.9	70.0	99999.9	7.8	978
	09/24/78	62.0	35.0	8.8	4.6	85.0	244.0	4.3	326
REC COUNT - 3 FOR 40									
41	01/10/78	15.1	19.6	14.1	13.0	160.0	148.8	16.0	484
	05/12/78	18.9	86.0	55.7	9.6	358.0	99999.9	18.0	798
	09/20/78	20.0	108.5	43.5	7.4	274.0	302.6	33.0	638
REC COUNT - 3 FOR 41									
42	01/10/78	39.5	29.3	15.2	9.9	141.7	183.0	2.7	358
	05/12/78	20.3	35.9	14.9	8.4	771.0	99999.9	5.8	1416
	09/24/78	39.0	67.6	17.5	6.6	105.0	225.7	12.0	380
REC COUNT - 3 FOR 42									

```
                              WATER QUALITY DATA FROM  WELLS IN POWDER RIVER BASIN
                                                                                              REPORT DATE -  78/12/18.

      WELL NO.      DATE          NA        CA        MG         K       SULFATE    BICARB      CL        TDS
                    COLLECT       MG/L      MG/L      MG/L       MG/L    MG/L       MG/L        MG/L      MG/L

 43                 01/10/78      8.8       30.6      17.5       27.5     33.2        739.3      2.9       488
                    05/04/78      7.8       39.1      15.8        4.4     38.0      99999.9      4.9       509
                    09/24/78      8.0       58.0      18.6        4.0     28.0      99999.9      6.4       236

        REC COUNT -    3 FOR 43

 44                 01/09/78     20.6       19.1      17.5        8.0    187.0        375.8      4.3      1489
                    05/11/78     15.6       17.2      18.7        9.8    160.0      99999.9     12.0      1127
                    09/24/78     15.0       19.3      23.7        8.0    105.0      99999.9     11.0       384

        REC COUNT -    3 FOR 44

 45                 05/04/78     27.0      103.0      72.4       14.8    483.0      99999.9      8.3      1278
                    09/24/78    235.0      234.0      71.0       14.0    477.0        439.2     11.0      1074

        REC COUNT -    2 FOR 45

 46                 01/09/78     17.9      182.7      45.0       32.6    332.0        229.4      4.2       692
                    05/11/78     10.4      147.7      45.6        8.4    178.0      99999.9      6.9       741
                    09/24/78      8.6       83.0      32.0        6.5    156.0        219.6      6.6       442

        REC COUNT -    3 FOR 46

 47                 01/11/78    553.6        9.2       7.8        2.8    549.0        424.6      3.8      1224
                    05/03/78    780.0        7.6       5.0        4.6    537.0      99999.9     11.5      1866

        REC COUNT -    2 FOR 47

 48                 01/12/78    637.7      160.1      52.0       11.0   1360.0        399.4     10.5      2046
                    05/03/78    760.0       23.1      19.7       10.2   1221.0      99999.9     11.5      2714
                    09/27/78    718.0       71.4      36.3        6.0   1185.0        817.4     15.0      2318

        REC COUNT -    3 FOR 48

 49                 05/03/78    520.0       22.6      18.7        9.9    717.0      99999.9     17.9       792

        REC COUNT -    1 FOR 49

 5                  01/24/78    440.0      108.0     112.0       15.0   1700.0        348.9     16.0      1460
                    05/08/78    364.0       51.7     101.5        9.7    944.0      99999.9     12.5      1778
                    09/30/78    486.0      150.0     127.0        8.1   1200.0        512.4     36.0      2760

        REC COUNT -    3 FOR 5

 50                 01/23/78    457.0        3.9       3.9        6.4    109.8        339.2     14.0       614
                    05/03/78    440.0        3.9       4.3        6.1    105.0      99999.9     29.0       972
                    09/27/78    393.5        6.5       4.4        4.0     87.0        976.0     38.0       771

        REC COUNT -    3 FOR 50

 51                 09/27/78     88.0      116.0     117.1        8.6    637.0        408.7     15.0      1268
```

```
  WELL NO.        DATE          NA         CA          MG         K          SULFATE      BICARB       CL          TDS
                  COLLECT       MG/L       MG/L        MG/L       MG/L       MG/L         MG/L         MG/L        MG/L

     REC COUNT -    1 FOR 51

 52               09/27/78      43.5       105.0       64.6        7.1       300.0        378.2        17.0         746

     REC COUNT -    1 FOR 52

 53               05/11/78      48.0       193.6      242.0      168.0      5176.0      99999.9       135.0        6721
                  09/27/78     134.0       234.0      378.4       14.0      4953.0        512.4       180.0        7873

     REC COUNT -    2 FOR 53

 54               01/13/78      20.5        12.3        4.1        3.4       333.6        151.3        12.0         594

     REC COUNT -    1 FOR 54

 54A              09/27/78     178.0        14.0        3.1        2.4       240.0        158.6        16.0         426

     REC COUNT -    1 FOR 54A

 54B              09/27/78     142.0         4.0         .7        2.1       164.0      99999.9        15.0         364

     REC COUNT -    1 FOR 54B

 55               01/13/78     136.2         6.2        1.7        2.7       231.5        417.2         9.0         374
                  05/10/78     154.1         5.3        1.8        2.4       160.0      99999.9        18.0         990
                  09/27/78     160.0        15.0        4.0        2.5        62.0      99999.9        15.0         431

     REC COUNT -    3 FOR 55

 56               05/01/78     290.0         1.8        1.9        2.1       141.0      99999.9        15.5         812
                  09/27/78     318.0         3.2        1.6        1.8       138.0        634.4        23.0         760

     REC COUNT -    2 FOR 56

 57               01/13/78     335.5         2.3        1.8        2.4       173.6        517.3         8.0         742
                  05/02/78     380.0         1.4        1.8        2.1       160.0      99999.9        14.3         814
                  09/27/78     324.5         3.2        1.4        2.0       138.0        683.2        17.0         705

     REC COUNT -    3 FOR 57

 59               01/13/78     338.7         4.3        3.1        3.4         1.0        148.8        23.5         578
                  05/02/78     240.0         3.6        3.1        3.6        88.0      99999.9         3.3         766
                  09/24/78     295.0         5.7        3.2        2.6          .0        780.8        48.0         569

     REC COUNT -    3 FOR 59

 6                01/24/78      20.0        43.0       22.0        8.0        73.2        268.4        11.6        1182
                  05/09/78      22.8        46.7       15.4       12.4       113.0      99999.9        12.0        1732
                  09/30/78      36.0        60.3       34.2       10.0        96.0        402.6        41.0         353

     REC COUNT -    3 FOR 6
```

WATER QUALITY DATA FROM WELLS IN POWDER RIVER BASIN

REPORT DATE - 78/12/18.

WELL NO.	DATE COLLECT	NA MG/L	CA MG/L	MG MG/L	K MG/L	SULFATE MG/L	BICARB MG/L	CL MG/L	TDS MG/L
60	01/09/78	89.5	9.7	1.4	1.4	116.6	234.2	5.2	708
REC COUNT - 1 FOR 60									
61	01/13/78	220.3	4.2	1.4	2.8	18.6	87.8	10.5	412
	05/10/78	.9	3.3	3.3	2.7	.0	99999.9	17.0	499
	09/24/78	197.0	5.7	1.5	2.1	.0	634.4	28.0	458
REC COUNT - 3 FOR 61									
62	05/12/78	10.1	1.3	2.4	1.2	69.0	99999.9	14.5	507
	09/24/78	115.0	2.3	.6	1.2	82.0	99999.9	15.0	191
REC COUNT - 2 FOR 62									
63	01/09/78	117.5	2.6	.6	130.8	91.4	246.4	7.2	240
	05/12/78	9.2	1.3	2.5	1.4	86.0	99999.9	13.8	596
	09/24/78	114.0	2.3	.7	1.4	85.0	99999.9	20.0	255
REC COUNT - 3 FOR 63									
64	05/12/78	120.0	164.0	436.0	12.1	2318.0	99999.9	71.0	4314
	09/20/78	210.0	294.0	199.0	19.0	1489.0	634.4	5.2	2651
REC COUNT - 2 FOR 64									
65	05/03/78	74.0	42.0	43.0	.0	106.0	99999.9	6.6	522
	09/24/78	80.0	66.0	27.0	4.0	130.0	451.4	7.6	518
REC COUNT - 2 FOR 65									
66	05/05/78	123.0	95.0	149.0	11.8	850.0	99999.9	29.0	1450
	09/20/78	140.0	200.0	85.0	9.0	882.0	329.4	33.0	1556
REC COUNT - 2 FOR 66									
67	05/02/78	380.0	81.0	238.0	14.7	1200.0	99999.9	12.0	3188
	09/20/78	266.0	215.0	176.0	12.0	1390.0	585.6	12.0	2331
REC COUNT - 2 FOR 67									
67A	05/02/78	220.0	49.0	43.0	11.8	3200.0	99999.9	8.8	3774
	09/20/78	90.0	180.0	295.3	8.0	2542.0	.0	10.0	3577
REC COUNT - 2 FOR 67A									
69	05/11/78	486.0	5.6	27.7	9.5	609.0	99999.9	18.0	1762
REC COUNT - 1 FOR 69									
7	01/24/78	99999.9	9999.9	9999.9	99999.9	3275.0	523.4	9999.9	1084

```
                                                                                      REPORT DATE -  78/12/18.
   WELL NO.        DATE            NA           CA          MG          K         SULFATE      BICARB        CL          TDS
                   COLLECT         MG/L         MG/L        MG/L        MG/L      MG/L         MG/L          MG/L        MG/L
 7
                  05/09/78       1150.0        290.0       523.0       12.9      2571.0      99999.9        50.0        4548
                  09/30/78        688.0        242.0       293.0       11.2      2280.0        866.2        79.0        4732
     REC COUNT -    3 FOR 7

 7A
                  05/09/78       1049.0        104.0       211.0       11.4      1636.0      99999.9        30.7        2778
                  09/30/78        696.0        133.0       136.0        9.6      1500.0        671.0        46.0        3200
     REC COUNT -    2 FOR 7A

 70               09/20/78        296.0        150.0        93.0        6.1       820.0        561.2        35.0        1712
     REC COUNT -    1 FOR 70

 71               09/20/78        238.0         34.0         9.0        3.0       409.0        268.4        10.0         766
     REC COUNT -    1 FOR 71

 72               09/20/78        133.0        271.0        63.0        7.5       856.0        280.6         8.0        1314
     REC COUNT -    1 FOR 72

 73               09/20/78        100.0         22.0         2.3        3.6        97.0        231.8         6.0         350
     REC COUNT -    1 FOR 73

 8
                  01/24/78        130.0         48.0       130.0       16.0       846.0         83.0         8.5        1304
                  05/09/78        152.7         18.7       153.9       13.1       805.0      99999.9        13.0        1316
                  09/15/78        133.0         96.0       148.9       13.0      1001.0        305.0        15.0        1862
     REC COUNT -    3 FOR 8

 8A
                  05/09/78        226.0        218.0       450.0       13.5      1411.0      99999.9        18.0        2404
                  09/15/78        157.0        217.3       215.5       13.0      1298.0        500.2        18.0        2673
     REC COUNT -    2 FOR 8A

 8B               09/15/78         96.0        116.6       153.1       10.0       810.0      99999.9        40.0        1582
     REC COUNT -    1 FOR 8B

 9
                  05/09/78        602.0          6.7         8.2        5.0       355.0      99999.9         9.5        1436
                  09/30/78        536.0         19.1        12.0        4.0       310.0       1098.0        10.5        1400
     REC COUNT -    2 FOR 9

      RECORD  TOTAL   207
     102 BREAKS FOR WELLNO
```

```
                                                                                              REMARKS
WELL NO.   DATE       NITRATE   BORON   HARDNESS   TOC       U        THORIUM
           COLLECT    -N-MG/L   MG/L    MG/L       MG/L   MICROG/L  MICROG/L

1          01/24/78     1.9      .00      60.9      3.90     999       9999    PO4=.22
           05/08/78      .1      .11     135.0      1.50     999       9999    FE=08.1MG/L
           09/15/78     1.7      .20     114.0     12.39       1         10    FE=14.5 MG/L,LIGHT SEDIMENT,LAB FILTERED

      REC COUNT -   3 FOR 1

10         05/09/78      .0      .31     647.0      4.50     999       9999    FE=08.5 MG/L

      REC COUNT -   1 FOR 10

105A       09/20/78      .1      .13     151.0      2.90       1         20    FE=2.5 MG/L,DIRTY,LAB FILTERED

      REC COUNT -   1 FOR 105A

105B       09/20/78    999.9  9999.99  99999.9    999.99       1         10    FE=1.0 MG/L,DIRTY,UNACIDIFIED SAMPLE BROKE

      REC COUNT -   1 FOR 105B

105C       09/20/78      .0      .13     129.0      2.59       1         10    FE=4.0 MG/L,NO NO3-LT 0.1 MG/L,LAB FILTERED

      REC COUNT -   1 FOR 105C

11         01/25/78     4.5      .00     233.0      2.80     999       9999    PO4=.01
           05/10/78    11.0     2.34     767.0      3.09     999       9999    FE=00.0 MG/L
           09/15/78     6.8     3.00     683.0      2.90       8         10    FE=0.0 MG/L,LIGHT COLOR,NO FE-LT 0.1 MG/L,LAB FILTERED

      REC COUNT -   3 FOR 11

12         01/25/78     2.1      .00     313.0      5.00     999       9999    PO4=.08
           05/10/78      .9      .63     376.0      4.19     999       9999    FE=00.0 MG/L ,
           09/15/78      .3     1.00     380.0      3.90      22         20    FE=0.4 MG/L,LAB FILTERED

      REC COUNT -   3 FOR 12

13         01/25/78      .4      .00      32.0      3.59     999       9999    PO4=0.0
           05/10/78      .1      .25      90.0      3.80     999       9999    FE=00.0 MG/L
           09/15/78      .3      .47      32.0      4.10       1         10    FE=0.1 MG/L,LAB FILTERED

      REC COUNT -   3 FOR 13

14         01/25/78      .1      .00     492.0      2.40     999       9999    PO4=0.0
           05/10/78      .0      .22     632.0      2.20     999       9999    FE=04.4 MG/L ,
           09/15/78      .0      .40     606.0      2.09       8         10    FE=2.0 MG/L,NO N-LT 0.1 MG/L,LAB FILTERED

      REC COUNT -   3 FOR 14

15         01/24/78      .1      .00      18.0      3.30     999       9999    PO4=0.0
           05/10/78      .0      .08      30.0      2.00     999       9999    FE=00.0 MG/L ,
           09/27/78      .1      .20      17.0      1.00       1         10    FE=0.0 MG/L,NO FE-LT 0.1 MG/L,LAB FILTERED

      REC COUNT -   3 FOR 15
```

```
WELL NO.      DATE     NITRATE  BORON  HARDNESS  TOC     U        THORIUM                          REMARKS
              COLLECT  -N-MG/L  MG/L   MG/L      MG/L  MICROG/L MICROG/L

16            01/25/78      .1  9999.99    15.0   2.90   999        9999  PO4=.04
              05/10/78      .0      .05    60.0   2.50   999        9999  FE=00.0 MG/L ,
              09/15/78      .0      .18    15.0   2.40     1          10  FE=0.0 MG/L,NO N-LT 0.1 MG/L,LAB FILTERED

         REC COUNT -    3 FOR 16

17            01/23/78      .1      .00    30.0   2.90   999        9999  PO4=0.0
              05/10/78      .4      .13  1218.0   1.20   999        9999  FE=32.6 MG/L  ,
              09/15/78     2.2      .33  1259.0  11.20     9          10  FE=4.0 MG/L,LIGHT ORANGE,LAB FILTERED

         REC COUNT -    3 FOR 17

18            01/26/78     1.1      .00    52.0   1.60   999        9999  PO4=.23
              05/10/78      .0      .04   105.0   4.00   999        9999  FE=05.5 MG/L
              09/27/78      .5      .20    88.0   4.30     1          10  FE=11.7 MG/L,ORANGE, LAB FILTERED

         REC COUNT -    3 FOR 18

19A           01/26/78     2.0      .00   183.0   2.59   999        9999  PO4=.15
              05/11/78     1.9      .33   602.0    .00   999        9999  FE=01.6 MG/L  ,
              09/15/78     2.7      .34   574.0   8.20     9          30  FE=0.4 MG/L,LAB FILTERED

         REC COUNT -    3 FOR 19A

19B           01/26/78     1.4     1.50   149.0   3.50   999        9999  PO4=.28
              05/11/78      .4      .10   105.0   7.00   999        9999  FE=01.9 MG/L
              09/15/78      .0      .30    54.6   6.69     1          10  FE=3.0 MG/L,VERY DIRTY,NO N-LT 0.1 MG/L,LAB FILTERED

         REC COUNT -    3 FOR 19B

19C           01/26/78     1.4     1.50    55.0   2.20   999        9999  PO4=.36
              05/11/78     1.6      .25  1165.0  10.16   999        9999  FE=00.6 MG/L  ,
              09/15/78      .2      .41   232.0   6.69     1          10  FE=2.0 MG/L,LIGHT SEDIMENT,LAB FILTERED

         REC COUNT -    3 FOR 19C

19D           01/26/78     2.3     1.50   116.0   3.00   999        9999  PO4=.38
              05/11/78      .0      .15   196.0   8.10   999        9999  FE=01.5 MG/L  ,
              09/15/78      .0      .30   167.0   3.90     4          10  FE=2.0 MG/L,DIRTY WATER,NO N-LT 0.1 MG/L,LAB FILTERED

         REC COUNT -    3 FOR 19D

19E           01/26/78     1.7     1.50    34.0   1.60   999        9999  PO4=.39
              05/11/78     2.5      .14   376.0   9.50   999        9999  FE=5.5
              09/15/78     2.5      .36   463.0   3.70     8          10  FE=14.0 MG/L,VERY DIRTY,LAB FILTERED

         REC COUNT -    3 FOR 19E

2             05/08/78      .0      .13   135.0   1.50   999        9999  FE=00.0 MG/L,
              09/30/78      .5      .27    72.0   1.10     2          10  FE=0.1 MG/L,LAB FILTERED
```

```
                                                                                     REMARKS
 WELL NO.     DATE      NITRATE  BORON  HARDNESS   TOC     U         THORIUM
              COLLECT   -N-MG/L  MG/L   MG/L       MG/L  MICROG/L  MICROG/L

 20           01/26/78    1.6     .00   1089.0      .30    999        9999    PO4=0.0
              05/11/78    1.4     .20    978.0     7.00    999        9999    FE=00.0 MG/L ,
              09/31/78    5.2     .42   1227.0     4.69      8          10    FE=0.4 MG/L,LAB FILTERED

         REC COUNT -    3 FOR 20

 21           01/23/78     .1    1.50     16.0     7.30    999        9999    PO4=0.0

         REC COUNT -    1 FOR 21

 22           01/26/78    5.4    1.50     51.0     1.60    999        9999    PO4=0.0
              05/25/78    1.0     .11    267.0     3.59    999        9999    FE= 0.00 MG/L,
              09/29/78    2.6     .23    194.0     3.90      1          10    FE=2.0 MG/L,LAB FILTERED

         REC COUNT -    3 FOR 22

 22A          05/25/78    4.2     .21     95.0     7.10    999        9999    FE= 0.28 MG/L,
              09/29/78    1.6     .20    126.0     4.50      1          10    FE=1.0 MG/L,LIGHT SEDIMENT,LAB FILTERED

         REC COUNT -    2 FOR 22A

 23           01/26/78    1.2     .00    671.0     1.20    999        9999    PO4=.07
              05/10/78     .0     .13    496.0     2.50    999        9999    FE=02.8 MG/L ,
              09/29/78     .5     .24    485.0     2.70      1          10    FE=2.0 MG/L,LIGHT ORANGE,LAB FILTERED

         REC COUNT -    3 FOR 23

 24           02/06/78    7.3     .00     18.0     5.40    999        9999    PO4=.12
              05/02/78     .0     .00     25.0     3.09    999        9999    FE=01.2 MG/L ,
              09/15/78     .2     .41     29.0      .20      1        9999    FE=0.2 MG/L,LAB FILTERED

         REC COUNT -    3 FOR 24

 251A         05/25/78     .6     .43    348.0     2.70    999        9999    FE= 1.48 MG/L,
              09/06/78     .3     .24    339.0     2.00      1          10    NO FE-LT 0.1 MG/L,LAB FILTERED

         REC COUNT -    2 FOR 251A

 251B         05/25/78     .4     .46    364.0     3.00    999        9999    FE= 1.32 MG/L,
              09/06/78     .6     .36    495.0     2.09      1          20    FE=1.0 MG/L,LAB FILTERED

         REC COUNT -    2 FOR 251B

 2514A        05/25/78     .2    1.19    753.0     9.80    999        9999    FE=46.80 MG/L,

         REC COUNT -    1 FOR 2514A

 2514AC       05/25/78     .4     .41   1660.0    94.60    999        9999    FE=13.20 MG/L,

         REC COUNT -    1 FOR 2514AC
```

```
                              WATER QUALITY DATA FROM  WELLS IN POWDER RIVER BASIN                                          PAGE   4

                                                                                                                  REPORT DATE -  78/12/18.

  WELL NO.      DATE      NITRATE  BORON  HARDNESS  TOC    U       THORIUM                          REMARKS
                COLLECT   -N-MG/L  MG/L   MG/L      MG/L  MICROG/L MICROG/L

2514B           05/25/78      .2    2.06   1418.0    4.00   999      9999   FE= 4.11 MG/L,

         REC COUNT -   1 FOR 2514B

252A            09/06/78     1.6     .21   1169.0    5.30     1      9999   FE=1.6 MG/L,VERY HIGH SEDIMENT,LAB FILTERED

         REC COUNT -   1 FOR 252A

252B            09/06/78     2.8     .20   1150.0    6.90     7        10   FE=0.9 MG/L, SEDIMENT, LAB FILTERED

         REC COUNT -   1 FOR 252B

252C            05/25/78      .6     .32     64.6    4.00   999      9999   FE= 0.09 MG/L,
                09/06/78     1.2     .22    472.0    6.50     1        10   FE=2.6 MG/L, SEDIMENT, LAB FILTERED

         REC COUNT -   2 FOR 252C

253A            05/25/78      .5     .16     11.4    8.80   999      9999   FE= 0.00 MG/L,
                09/06/78     1.4     .13     47.0    4.50     3        10   FE=0.2 MG/L, LAB FILTERED

         REC COUNT -   2 FOR 253A

253B            05/25/78      .3     .21     56.0    2.30   999      9999   FE= 0.00 MG/L,
                09/06/78      .0     .10     38.0    3.00     1        20   FE=2.8 MG/L, NO NO3-LESS THAN 0.1 MG/L,LAB FILTERED

         REC COUNT -   2 FOR 253B

253C            05/25/78     1.2     .22     24.0    3.80   999      9999   FE= 0.00 MG/L,
                09/06/78      .3     .24     28.0   28.70     1        20   FE=1.2 MG/L,EXTREMELY MUDDY,LAB FILTERED

         REC COUNT -   2 FOR 253C

254A            09/06/78      .8     .12    565.0    2.59     1        10   FE=1.0 MG/L, SEDIMENT,LAB FILTERED

         REC COUNT -   1 FOR 254A

254B            09/06/78      .0     .13    584.0    2.09     1        20   FE=2.6 MG/L, LOW SEDIMENT,NO NO3-LT 0.1 MG/L,LAB FILTE

         REC COUNT -   1 FOR 254B

254C            09/06/78      .0     .13    113.0    3.59     1        10   FE=0.2 MG/L,NO NO3-LESS THAN 0.1 MG/L,LAB FILTERED

         REC COUNT -   1 FOR 254C

255A            05/25/78      .4     .10    624.0    1.20   999      9999   FE= 0.00 MG/L,
                09/06/78      .4     .05    622.0    1.79     1        20   FE=1.8 MG/L,SEDIMENT, LAB FILTERED

         REC COUNT -   2 FOR 255A

255B            05/25/78      .4     .13    105.0    4.50   999      9999   FE= 0.24 MG/L,
                09/06/78      .0     .11     94.0    1.60     1        30   FE=0.7 MG/L,LOW SEDIMENT, NO NO3-LT 0.1 MG/L,LAB FILTE
```

WELL NO.	DATE COLLECT	NITRATE -N-MG/L	BORON MG/L	HARDNESS MG/L	TOC MG/L	U MICROG/L	THORIUM MICROG/L	REMARKS
	REC COUNT - 2 FOR 255B							
255C	05/25/78	.3	.25	284.0	2.59	999	9999	FE= 0.00 MG/L,
	09/06/78	.0	.15	245.0	2.40	1	10	FE=0.4 MG/L, LOW SEDIMENT, NO NO3-LT 0.1 MG/L,LAB FILT
	REC COUNT - 2 FOR 255C							
256A	09/06/78	.2	.13	33.0	7.50	1	20	FE=0.6 MG/L, CLOUDY, SEDIMENT, LAB FILTERED
	REC COUNT - 1 FOR 256A							
256B	09/06/78	1.1	.13	924.0	3.20	4	10	FE=0.5 MG/L, LOW SEDIMENT, LAB FILTERED
	REC COUNT - 1 FOR 256B							
256C	09/06/78	.5	.10	604.0	2.90	1	10	FE=0.9 MG/L, HIGH SEDIMENT, LAB FILTERED
	REC COUNT - 1 FOR 256C							
256D	09/06/78	.0	.10	61.0	3.40	1	10	FE=4.1 MG/L, SEDIMENT,NO NO3-LT 0.1 MG/L,LAB FILTERED
	REC COUNT - 1 FOR 256D							
256E	09/06/78	.1	.10	236.0	3.50	1	20	FE=0.6 MG/L, ORANGE SEDIMENT, LAB FILTERED
	REC COUNT - 1 FOR 256E							
256F	09/06/78	.4	.05	424.0	7.90	1	10	FE=1.4 MG/L, LOW SEDIMENT, LAB FILTERED
	REC COUNT - 1 FOR 256F							
258A	05/25/78	.5	.54	624.0	3.80	999	9999	FE= 0.00 MG/L,
	09/06/78	.0	.46	509.0	5.40	2	10	FE=0.4 MG/L,NO NO3-LESS THAN 0.1 MG/L,LAB FILTERED
	REC COUNT - 2 FOR 258A							
258B	05/25/78	1.2	.06	57.0	15.50	999	9999	FE= 0.00 MG/L,
	09/06/78	.9	.10	94.0	3.00	1	10	FE=1.2 MG/L, SEDIMENT,LAB FILTERED
	REC COUNT - 2 FOR 258B							
258C	05/25/78	.2	.13	753.0	3.20	999	9999	FE= 1.10 MG/L,
	09/06/78	.0	.12	735.0	21.00	3	30	FE=0.5 MG/L, SEDIMENT, NO NO3-LT 0.1 MG/L, LAB FILTERE
	REC COUNT - 2 FOR 258C							
26	05/09/78	.0	.20	30.0	2.40	999	9999	FE=00.0 MG/L ,
	09/15/78	.2	.35	7.0	1.20	1	10	NO FE-LT 0.1 MG/L,LAB FILTERED
	REC COUNT - 2 FOR 26							

WELL NO.	DATE COLLECT	NITRATE -N-MG/L	BORON MG/L	HARDNESS MG/L	TOC MG/L	U MICROG/L	THORIUM MICROG/L	REMARKS
27A	09/15/78	.1	.57	54.0	4.19	1	9999	FE=22.0 MG/L,VERY DIRTY,LAB FILTERED
REC COUNT - 1 FOR 27A								
28A	05/10/78	.0	.05	105.0	2.20	999	9999	FE=08.1 MG/L ,
	09/27/78	.7	.20	99.0	2.09	1	10	FE=2.0 MG/L,ORANGE COLOR,LAB FILTERED
REC COUNT - 2 FOR 28A								
28B	05/10/78	.0	.20	60.0	3.87	999	9999	FE=00.0 MG/L ,
	09/15/78	.1	.25	9.0	.60	1	20	NO FE-LT 0.1 MG/L,LAB FILTERED
REC COUNT - 2 FOR 28B								
29	05/11/78	.0	20.00	15.0	1.90	999	9999	FE=00.0 MG/L ,
	09/31/78	.6	.41	2.0	1.10	1	10	FE=1.0 MG/L,NO SO4-LT 2.0 MG/L,LAB FILTERED
REC COUNT - 2 FOR 29								
3	01/24/78	.4	1.50	357.0	3.30	999	9999	PO4=.16
	05/08/78	.0	.27	541.0	5.80	999	9999	FE=02.0 MG/L
	09/15/78	.3	.85	1215.0	7.50	13	10	FE=0.8 MG/L,LAB FILTERED
REC COUNT - 3 FOR 3								
30	09/15/78	1.6	.55	492.0	1.10	3	10	FE=0.1 MG/L,LAB FILTERED
REC COUNT - 1 FOR 30								
4	01/24/78	1.2	1.50	1479.0	5.60	999	9999	PO4=0.0
	05/08/78	.2	.38	1308.0	5.80	999	9999	FE=00.7 MG/L
	09/30/78	1.5	.67	1320.0	5.69	1	10	FE=1.0 MG/L,LAB FILTERED
REC COUNT - 3 FOR 4								
40	01/10/78	.2	.00	194.0	.80	999	9999	PO4=.00
	05/12/78	.0	.11	180.0	4.30	999	9999	FE=00.6 MG/L ,
	09/24/78	.2	.10	117.0	.89	1	10	FE=0.7 MG/L,LAB FILTERED
REC COUNT - 3 FOR 40								
41	01/10/78	.1	.00	177.0	13.50	999	9999	PO4=0.00
	05/12/78	.0	.20	511.0	6.50	999	9999	FE=44.0 MG/L ,
	09/20/78	.4	.20	496.0	8.00	9	10	FE=50.0 MG/L,ORANGE COLOR,LAB FILTERED
REC COUNT - 3 FOR 41								
42	01/10/78	.1	.00	208.0	1.50	999	9999	PO4=.00
	05/12/78	.0	.10	256.0	1.50	999	9999	FE=00.1 MG/L ,
	09/24/78	.1	.10	224.0	.70	1	10	FE=0.4 MG/L,LAB FILTERED

WATER QUALITY DATA FROM WELLS IN POWDER RIVER BASIN

REPORT DATE - 78/12/18.

WELL NO.	DATE COLLECT	NITRATE -N-MG/L	BORON MG/L	HARDNESS MG/L	TOC MG/L	U MICROG/L	THORIUM MICROG/L	REMARKS
43	01/10/78	.2	.00	239.0	2.90	999	9999	PO4=.06
	05/04/78	.0	.17	160.0	2.45	999	9999	FE=01.7 MG/L ,
	09/24/78	.1	.13	214.0	1.79	1	10	FE=1.1 MG/L,ORANGE COLOR,LAB FILTERED
	REC COUNT - 3 FOR 43							
44	01/09/78	.2	.00	179.0	3.40	999	9999	PO4=.19
	05/11/78	.0	.03	196.0	3.40	999	9999	FE=03.5 MG/L ,
	09/24/78	.0	.16	129.0	3.59	999	9999	FE=4.5 MG/L,DIRTY,NO NO3-LT 0.1 MG/L,LAB FILTERED
	REC COUNT - 3 FOR 44							
45	05/04/78	.0	.27	859.0	6.69	999	9999	FE=04.0 MG/L,
	09/24/78	.8	.28	896.0	6.00	1	10	FE=1.4 MG/L,LAB FILTERED
	REC COUNT - 2 FOR 45							
46	01/09/78	2.6	.00	507.0	5.10	999	9999	PO4=.00
	05/11/78	1.0	.10	406.0	2.59	999	9999	FE=00.2 MG/L ,
	09/24/78	.9	.20	360.0	2.80	6	10	FE=1.3 MG/L,LAB FILTERED
	REC COUNT - 3 FOR 46							
47	01/11/78	2.6	.00	75.0	3.20	999	9999	PO4=.00
	05/03/78	.1	.06	131.0	2.70	999	9999	FE=00.3 MG/L ,
	REC COUNT - 2 FOR 47							
48	01/12/78	3.8	.00	492.0	2.00	999	9999	PO4=.00
	05/03/78	2.0	.06	160.0	3.80	999	9999	FE=00.9 MG/L ,
	09/27/78	.9	.20	342.0	1.60	1	10	FE=1.0 MG/L,LAB FILTERED
	REC COUNT - 3 FOR 48							
49	05/03/78	1.7	.05	291.0	2.30	999	9999	FE=00.2 MG/L ,
	REC COUNT - 1 FOR 49							
5	01/24/78	.2	1.50	776.0	6.40	999	9999	PO4=2.2
	05/08/78	.0	.27	662.0	3.59	999	9999	FE=02.6 MG/L,
	09/30/78	.4	.60	990.0	2.80	3	10	FE=2.0 MG/L,LIGHT ORANGE,LAB FILTERED
	REC COUNT - 3 FOR 5							
50	01/23/78	6.3	.00	15.0	2.70	999	9999	PO4=.11
	05/03/78	.0	.06	.0	2.50	999	9999	FE=00.5 MG/L ,
	09/27/78	1.6	.24	34.0	2.09	1	10	FE=1.0 MG/L,DIRTY,LAB FILTERED
	REC COUNT - 3 FOR 50							
51	09/27/78	.3	.16	769.0	1.60	1	10	FE=3.0 MG/L,ORANGE COLOR,LAB FILTERED

```
                                                                                             REPORT DATE -  78/12/18.
 WELL NO.    DATE      NITRATE  BORON  HARDNESS  TOC    U         THORIUM                         REMARKS
             COLLECT   -N-MG/L  MG/L   MG/L      MG/L  MICROG/L  MICROG/L

          REC COUNT -    1 FOR 51

 52          09/27/78      .5     .17    506.0    1.60      7           30   FE=0.7 MG/L,LAB FILTERED

          REC COUNT -    1 FOR 52

 53          05/11/78      .0     .11   2978.0    1.60    999         9999   FE=06.2 MG/L ,
             09/27/78      .5     .26   2304.0    5.50      2           20   FE=5.6 MG/L,ORANGE COLOR,LAB FILTERED

          REC COUNT -    2 FOR 53

 54          01/13/78      .2     .00     56.0    1.29    999         9999   PO4=.00

          REC COUNT -    1 FOR 54

 54A         09/27/78     1.4     .11     59.0    1.79      1           10   FE=0.5 MG/L,LAB FILTERED

          REC COUNT -    1 FOR 54A

 54B         09/27/78      .0     .13     24.0    1.79      1           20   FE=3.0 MG/L, DIRTY,NO NO3-LT 0.1 MG/L,LAB FILTERED

          REC COUNT -    1 FOR 54B

 55          01/13/78      .1     .00     18.0     .10    999         9999   PO4=0.00
             05/10/78      .0     .06     60.0    5.80    999         9999   FE=00.0 MG/L ,
             09/27/78      .0     .11     62.0    2.30      1           10   FE=0.7 MG/L,LAB FILTERED

          REC COUNT -    3 FOR 55

 56          05/01/78      .0     .08    437.0    2.00    999         9999   FE=00.0 MG/L,
             09/27/78      .2     .24     34.0    1.60      1           10   NO FE-LT 0.1 MG/L,LAB FILTERED

          REC COUNT -    2 FOR 56

 57          01/13/78      .8    1.20     23.0     .80    999         9999   PO4=.21
             05/02/78      .0     .06     29.0    3.30    999         9999   FE=00.0 MG/L ,
             09/27/78      .3     .20     10.0    2.30      1           10   NO FE-LT 0.1 MG/L,LAB FILTERED

          REC COUNT -    3 FOR 57

 59          01/13/78      .3     .00       .0     .24    999         9999   PO4=.25
             05/02/78      .1     .04     87.0    3.30    999         9999   FE=00.5 MG/L ,
             09/24/78     2.2     .13     27.0    1.50      1           10   FE=2.1 MG/L,DIRTY,NO SO4-LT 2.0 MG/L,LAB FILTERED

          REC COUNT -    3 FOR 59

 6           01/24/78     1.1     .00    209.0    2.40    999         9999   PO4=.1
             05/09/78    13.0     .08    226.0    6.90    999         9999   FE=00.0 MG/L ,
             09/30/78      .3     .17    330.0    4.60      3           10   FE=2.5 MG/L,DEAD SKUNK IN WELL,LAB FILTERED
```

```
                                                                                     REMARKS
 WELL NO.   DATE       NITRATE  BORON   HARDNESS  TOC     U          THORIUM
            COLLECT    -N-MG/L  MG/L    MG/L      MG/L  MICROG/L  MICROG/L

 60         01/09/78      .2      .00       1.4   14.50    999        9999   PO4=0.07

      REC COUNT -   1 FOR 60

 61         01/13/78      .2      .00      18.0    1.10    999        9999   PO4=.00
            05/10/78      .0      .06      30.0    2.70    999        9999   FE=00.5 MG/L ,
            09/24/78      .3      .15      15.0    1.20      1          10   FE=0.2 MG/L,NO SO4-LT 2.0 MG/L,LAB FILTERED

      REC COUNT -   3 FOR 61

 62         05/12/78      .0      .05      15.0    1.90    999        9999   FE=00.0 MG/L ,
            09/24/78      .1      .10      10.0     .50      1          10   NO FE-LT 0.1 MG/L,LAB FILTERED

      REC COUNT -   2 FOR 62

 63         01/09/78      .2      .00      32.1    2.09    999        9999   PO4=.04
            05/12/78      .0      .06      30.0    2.20    999        9999   FE=00.0 MG/L
            09/24/78      .1      .12       7.0     .60      1          10   FE=0.1 MG/L,LAB FILTERED

      REC COUNT -   3 FOR 63

 64         05/12/78      .0      .35        .0    6.60    999        9999   FE=00.1 MG/L ,
            09/20/78      .0      .28    1597.0    1.90     22          10   FE=4.0 MG/L,DIRTY,NO NO3-LT 0.1 MG/L,LAB FILTERED

      REC COUNT -   2 FOR 64

 65         05/03/78      .1      .09     436.0    4.00    999        9999   FE=00.3 MG/L ,
            09/24/78      .4      .13     350.0    2.30      1          10   FE=0.1 MG/L,LAB FILTERED

      REC COUNT -   2 FOR 65

 66         05/05/78      .0      .10     859.0    1.60    999        9999   FE=04.5 MG/L,
            09/20/78      .0      .24     866.0    4.19      2          20   FE=3.0 MG/L,ORANGE COLOR,NO NO3-LT 0.1 MG/L,LAB FILTER

      REC COUNT -   2 FOR 66

 67         05/02/78      .0      .06    2154.0    2.30    999        9999   FE=45.0 MG/L,
            09/20/78      .0      .26    1198.0    2.00      1          10   FE=12.0 MG/L,ORANGE COLOR,NO NO3-LT 0.1 MG/L,LAB FILTE

      REC COUNT -   2 FOR 67

 67A        05/02/78      .1      .21    1223.0    2.60    999        9999   FE=4.5
            09/20/78     3.8      .30     939.0    2.59      1          30   FE=59.0 MG/L,ORANGE COLOR,PH=4.7,LAB FILTERED

      REC COUNT -   2 FOR 67A

 69         05/11/78      .0      .10     196.0    8.10    999        9999   FE=01.1 MG/L ,

      REC COUNT -   1 FOR 69

 7          01/24/78   999.9  9999.99     300.0  999.99    999        9999   PO4=.99
```

```
WELL NO.    DATE      NITRATE  BORON  HARDNESS   TOC     U        THORIUM                      REMARKS
            COLLECT   -N-MG/L  MG/L   MG/L       MG/L  MICROG/L MICROG/L

 7          05/09/78      .1     .34  2000.0     5.60   999        9999   FE=03.5 MG/L
            09/30/78      .6     .51  1961.0     4.50    17          10   FE=2.0 MG/L,LIGHT ORANGE,LAB FILTERED

       REC COUNT -    3 FOR 7

 7A         05/09/78      .0     .34   887.0     3.70   999        9999   FE=05.5 MG/L
            09/30/78      .5     .60   889.0     3.00     2          10   FE=5.0 MG/L,HEAVY ORANGE SEDIMENT,LAB FILTERED

       REC COUNT -    2 FOR 7A

 70         09/20/78     1.6     .20   777.0     7.30     1          10   FE=2.0 MG/L,LIGHT ORANGE,LAB FILTERED

       REC COUNT -    1 FOR 70

 71         09/20/78     1.0     .12   134.0     1.70     1          10   FE=0.3 MG/L,LAB FILTERED

       REC COUNT -    1 FOR 71

 72         09/20/78      .0     .15   833.0     1.70     1          10   FE=0.3 MG/L,LAB FILTERED

       REC COUNT -    1 FOR 72

 73         09/20/78      .5     .13    58.0      .89    32          10   NO FE-LT 0.1 MG/L,LAB FILTERED

       REC COUNT -    1 FOR 73

 8          01/24/78     2.4     .00   656.0     2.00   999        9999   PO4=0.0
            05/09/78      .0     .15   727.0     1.17   999        9999   FE=03.9 MG/L ,
            09/15/78      .0     .30   920.0    28.79     1          10   FE=3.0 MG/L,ORANGE,NO N-LT 0.1 MG/L,LAB FILTERED

       REC COUNT -    3 FOR 8

 8A         05/09/78      .0     .25  1760.0    11.70   999        9999   FE=05.0 MG/L ,
            09/15/78      .0     .44  1480.0     4.40    13          10   FE=4.0 MG/L,DIRTY WATER,NO N-LT 0.1 MG/L,LAB FILTERED

       REC COUNT -    2 FOR 8A

 8B         09/15/78     2.1     .20  1019.0     2.30   999        9999   FE=0.4 MG/L,LAB FILTERED

       REC COUNT -    1 FOR 8B

 9          05/09/78      .2     .35   105.0     2.50   999        9999   FE=01.3 MG/L,
            09/30/78      .7     .53   107.0     1.10     2          10   FE=5.0 MG/L,LIGHT DIRT, LAB FILTERED

       REC COUNT -    2 FOR 9

         RECORD  TOTAL    207
        102 BREAKS FOR WELLNO
```

APPENDIX E

QUALITY ASSURANCE PROGRAM
FOR THE
HITTMAN ENVIRONMENTAL
CHEMICAL LABORATORY

HITTMAN ASSOCIATES, INC.
9151 RED BRANCH ROAD
COLUMBIA, MARYLAND 21045

SCOPE

This Quality Assurance Plan is designed to cover the following service areas:

- Sampling Plan Preparation
- Field Sampling and Flowrating
- Sample Handling and Chain of Custody
- Sample Physical and Chemical Analysis
- Equipment and Instrument Calibration
- Equipment and Instrument Testing and Maintenance
- Chemicals and Materials Controls
- Data Handling and Record Keeping

PURPOSE

The purpose of this QA Plan is to assure that laboratory results are of a consistently high quality commensurate with their intended use and to protect samples where appropriate for service as evidential matter in litigations.

QUALIFICATION REFERENCES

This QA plan is designed to qualify the Hittman Environmental Chemical Laboratory service, including field sampling services, under the procedural, methodology and equipment requirements of the following references.

1. Standard Methods for Examination of Water and Wastewater (14th Edition), APHA, AWWA and WPCF, Washington, DC, 1975.
2. Methods for the Chemical Analysis of Water and Wastes, MDQARC National Environmental Research Center, USEPA, Cincinnati, Ohio, 1974.
3. Handbook for Monitoring Industrial Wastewater, Technology Transfer, USEPA, Washington, D.C., August 1973.
4. Handbook for Analytical Quality Control in Water and Wastewater Laboratories, MDQARL, NERC, USEPA, Cincinnati, Ohio, June 1972.
5. NPDES Compliance Sampling Manual, Enforcement Division, Office of Water Enforcement, Compliance Branch USEPA, Washington, DC, June 1977.
6. Annual Book of Standards (Part 23), Water and Atmospheric Analysis, A.S.T.M., Philadelphia, Pa., 1973.
7. Federal Register, Vol. 38, No. 199, Part II, Guidelines Establishing Test Procedures for Analysis of Pollutants, October 16, 1973.
8. Federal Register, Vol. 40, No. 248, Part IV, Drinking Water Regulations, December 24, 1975.
9. Quality Assurance Handbook for Air Pollution Measurement Systems, EMSL, RTP, USEPA, January 1976.

INTRODUCTION

The Hittman Environmental Chemical Laboratory services cover a wide range of activities from air and water pollution to toxic substances and solid wastes for research and development, environmental impact assessment, pollution control in effluents and emissions and simple process control for industrial clients. Each one of these activities relies heavily on laboratory data and sampling/flowrating procedures, as a basis for research, development, process assessment, control compliance and/or capital expenditure decision making. Clearly a thorough and dependable quality assurance program is both justified and required. In order for such a program to be effective it must be understood by and adhered to by all operating personnel. In addition, it must have the complete and unqualified support of all management persons. Reliable and accurate equipment must be used. The QA program has high priority and in fact requires both analysts' and managers' continued attention.

Because the Hittman Environmental Chemical Laboratory does such a variety of work, this plan recognizes the variable needs of Quality Assurance in processing (1) Protocol I, Precision Samples (for research and pollution control compliance or enforcement uses); (2) Protocol II, Routine Samples (requiring normal accuracy and precision in results); and (3) Protocol III, Qualitative Samples (for order-of-magnitude concentrations). These three categories with differing accuracy and precision requirements are called Protocols. The end use of the data is then a vital factor in the determination of the level and depth of QC (quality control) needed.

This document is HAI's Quality Assurance standard. The various references cited should be noted and certain of them kept on hand in the laboratory for frequent use. Details on procedures, equipment and how to deal with exceptions will be found in the references. When questions persist, it is appropriate to seek acceptance from the U.S.E.P.A. laboratories or the client of nonstandard methodologies or equipment systems before their uses in critical sampling or analytical assignments.

RESPONSIBILITIES FOR QUALITY ASSURANCE

Each manager (including Project Engineers and Project Scientists) is responsible for seeing that Quality Assurance is conducted in a suitable professional manner in accordance with this QA Standard. The Hittman E.C.L. has a Quality Assurance Coordinator skilled in laboratory methods and data handling who is required to make periodic surveys of in-house laboratory procedures operations and records and to review sample planning, sampling/ flowrating and related procedures to insure continued compliance with this Quality Assurance Program. Once a year a brief report on QA will be made to the Laboratory Manager and Analytical Director with copies forwarded to the Director of the Technical Staff and the Vice President/General Manager.

Whenever Quality Assurance is pertinent on contracts and purchase agreements, a clause will be placed in the aforesaid documents to insure that proper QA procedures will be followed. Standard samples from the U.S.E.P.A. Environmental Monitoring and Support Laboratory (EMSL) and/or other suitable sources will be procured and run at least twice each year using selected parameters of concern. The client's project office, project engineer, or other representative responsible for QA is invited to make certain that those QA procedures are followed by reviewing records and when making a site visit to observe QA procedures.

PREFACE

The success of any project depends on sound data on which to make research, design and enforcement decisions. When this sound data is generated by an analytical chemical laboratory, every reasonable effort must be made to insure that the data is of continuously high quality. To aid the Hittman Environmental Chemical Laboratory (ECL) in achieving such results, this Quality Assurance Plan (QAP) has been developed. It is generally patterned after the U.S.E.P.A. Municipal Environmental Research Laboratory QAP.

Elements of this QAP which are particularly important with respect to the continuing successful performance of sampling and analytical chemical services are as follows:

- Comprehensive Sampling Plan Preparation
- Collecting, Identifying and Preserving Samples
- Accurate Flowrating
- Transporting and Storing Samples
- Physical and Chemical Analysis
- Biological Analysis
- Alternative Test Procedures
- Quality Control
- Special Cases
- Recording, Storing and Retrieving Data

The referenced procedures and methods for the above sections are shown in the following text. Any proposed deviations are to be documented in writing and submitted to the project officer for his approval. The report "Compilation of Methodology Used for Measuring Pollution Parameters of Sanitary Landfill Leachate" (EPA-600/3-75-011), may be useful as a guide in selecting specific methods.

Quality control is especially important in determining the significance of results. Two standard reference samples from the Environmental Monitoring and Support Laboratory (EMSL) shall be analyzed annually, and the results submitted to the project officer 20 days after receipt of such samples. Results shall also be presented in the final report in an appendix discussing quality control. In addition, the contractor shall routinely document analytical precision and accuracy for each analytical procedure employed and summarize the results in the final reports. An unknown sample, supplied by the SHWRD (Solid and Hazardous Waste Research Division) shall be analyzed by the contractor. The two reference and one unknown sample are to be analyzed using the procedures normally employed by the contractor.

In general, the ECL will comply with the Routine Analytical Protocol II, but where special analytical procedures are to be developed or possible litigation is involved, the Precision Analytical Protocol III will be used. When a client stipulates for cost-effective exploratory efforts the use of Qualitative Protocol I will be employed.

Figure 1 summarizes the procedures used and chain of costody for samples. Figure 2 summarize the people responsible and quality control reporting procedures.

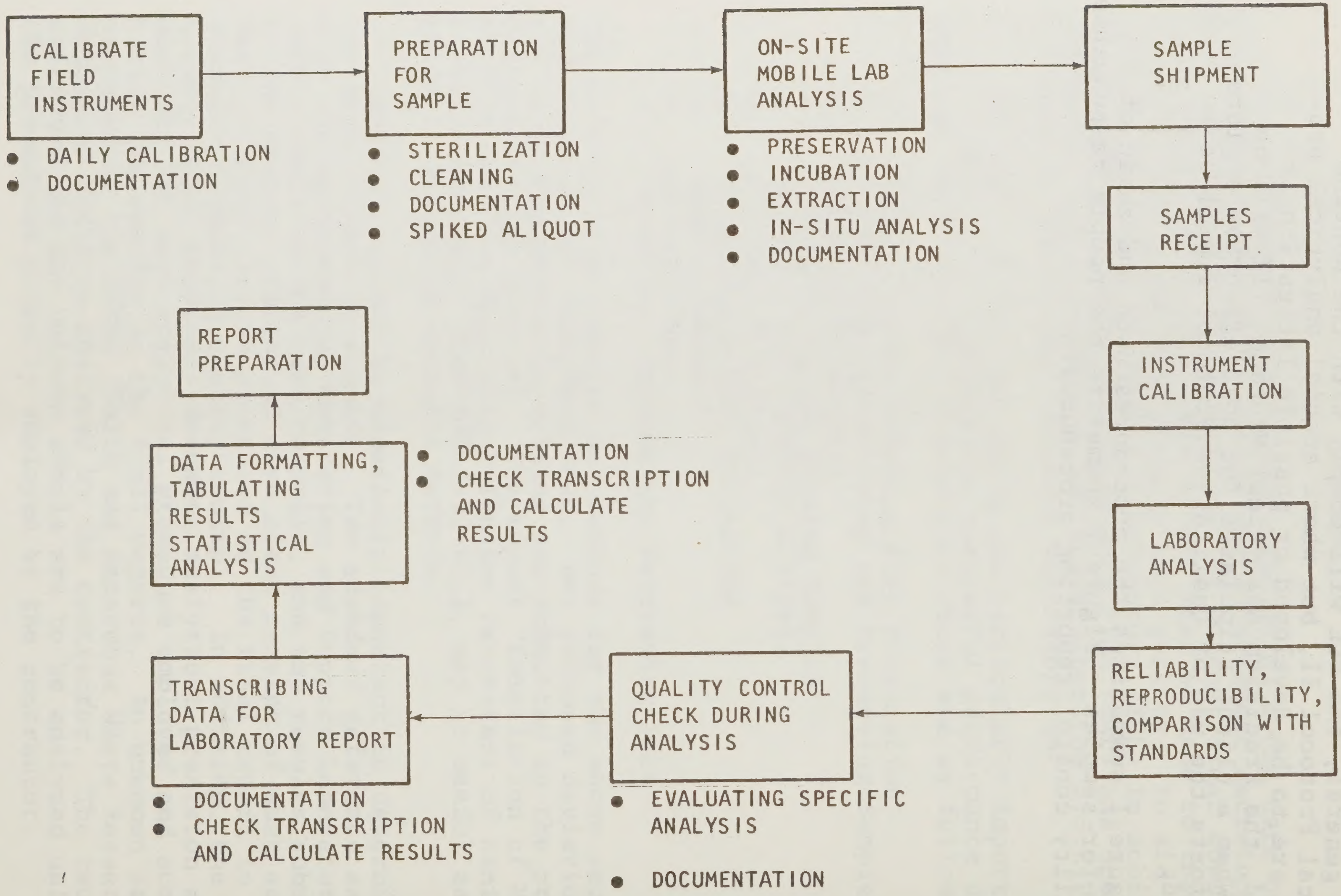

CALIBRATE FIELD INSTRUMENTS
● DAILY CALIBRATION
● DOCUMENTATION
PREPARATION FOR SAMPLE
● STERILIZATION
● CLEANING
● DOCUMENTATION
● SPIKED ALIQUOT
ON-SITE MOBILE LAB ANALYSIS
● PRESERVATION
● INCUBATION
● EXTRACTION
● IN-SITU ANALYSIS
● DOCUMENTATION
SAMPLE SHIPMENT
SAMPLES RECEIPT
INSTRUMENT CALIBRATION
LABORATORY ANALYSIS
RELIABILITY, REPRODUCIBILITY, COMPARISON WITH STANDARDS
QUALITY CONTROL CHECK DURING ANALYSIS
● EVALUATING SPECIFIC ANALYSIS
● DOCUMENTATION
TRANSCRIBING DATA FOR LABORATORY REPORT
● DOCUMENTATION
● CHECK TRANSCRIPTION AND CALCULATE RESULTS
DATA FORMATTING, TABULATING RESULTS STATISTICAL ANALYSIS
● DOCUMENTATION
● CHECK TRANSCRIPTION AND CALCULATE RESULTS
REPORT PREPARATION

Figure 1. Chain of Costody and Quality Control Procedures

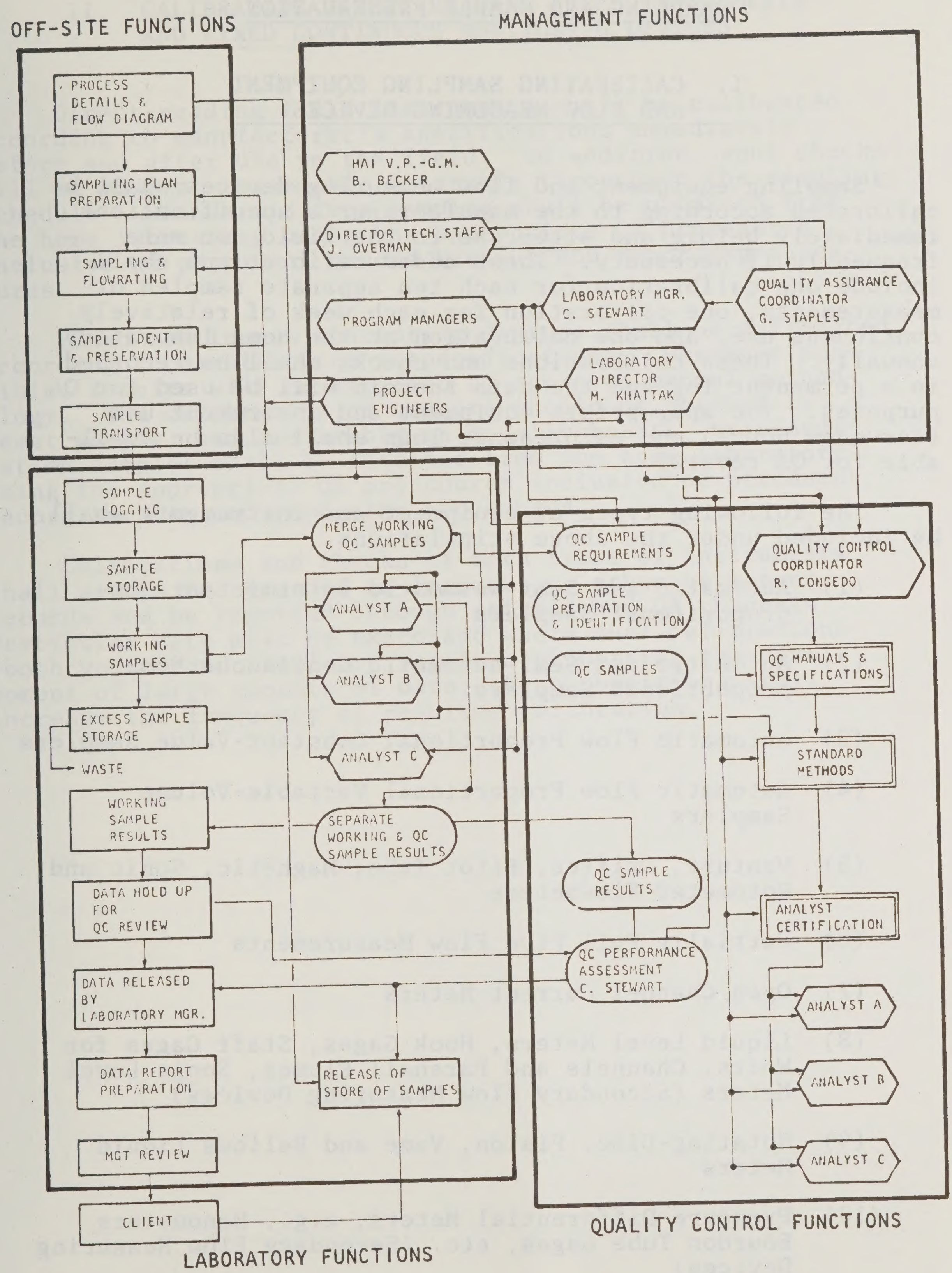

OFF-SITE FUNCTIONS
PROCESS DETAILS & FLOW DIAGRAM
SAMPLING PLAN PREPARATION
SAMPLING & FLOWRATING
SAMPLE IDENT. & PRESERVATION
SAMPLE TRANSPORT
MANAGEMENT FUNCTIONS
HAI V.P.-G.M. B. BECKER
DIRECTOR TECH.STAFF J. OVERMAN
PROGRAM MANAGERS
PROJECT ENGINEERS
LABORATORY MGR. C. STEWART
LABORATORY DIRECTOR M. KHATTAK
QUALITY ASSURANCE COORDINATOR G. STAPLES
SAMPLE LOGGING
SAMPLE STORAGE
WORKING SAMPLES
EXCESS SAMPLE STORAGE
WASTE
WORKING SAMPLE RESULTS
DATA HOLD UP FOR QC REVIEW
DATA RELEASED BY LABORATORY MGR.
DATA REPORT PREPARATION
MGT REVIEW
CLIENT
MERGE WORKING & QC SAMPLES
ANALYST A
ANALYST B
ANALYST C
SEPARATE WORKING & QC SAMPLE RESULTS
RELEASE OF STORE OF SAMPLES
LABORATORY FUNCTIONS
QC SAMPLE REQUIREMENTS
QC SAMPLE PREPARATION & IDENTIFICATION
QC SAMPLES
QUALITY CONTROL COORDINATOR R. CONGEDO
QC MANUALS & SPECIFICATIONS
STANDARD METHODS
QC SAMPLE RESULTS
QC PERFORMANCE ASSESSMENT C. STEWART
ANALYST CERTIFICATION
ANALYST A
ANALYST B
ANALYST C
QUALITY CONTROL FUNCTIONS

Figure 2. Persons Responsible and Quality Control Reporting Procedures

SAMPLING AND SAMPLE PRESERVATION

I. CALIBRATING SAMPLING EQUIPMENT AND FLOW MEASURING DEVICES

Sampling equipment and flow measuring devices shall be calibrated according to the manufacturer's specifications immediately before and after use in the field, or more frequently if necessary. These added calibrations shall include one calibration for each ten separate samples or measurements, one calibration for each week of relatively continuous use, and one calibration at the home laboratory annually. These calibrations and checks shall be recorded in a permanent log and the data therein will be used for QA purposes. The appropriate equipment and instrument use (services hours) and maintenance logs shall also be available for QA review.

The following types of equipment and instruments shall be included under the above stipulations.

(1) Automatic and Semi-automatic Intermittant Non-proportional Samplers

(2) Automatic and Semi-automatic Continuous Non-proportional Samplers

(3) Automatic Flow Proportional Constant-Value Samplers

(4) Automatic Flow Proportional Variable-Volume Samplers

(5) Venturi, Orifice, Pitot Tube, Magnetic, Sonic and Rotometer Flowmeters

(6) Partially Full Pipe Flow Measurements

(7) Open Channel Current Meters

(8) Liquid Level Meters, Hook Gages, Staff Gages for Weirs, Channels and Parshall Flumes, Sonic Level Meters (Secondary Flow Measuring Devices)

(9) Nutating-Disc, Piston, Vane and Bellows Liquid Meters

(10) Pressure Differential Meters, e.g., Manometers Bourdon Tube Gages, etc. (Secondary Flow Measuring Devices)

II. CALIBRATING DIRECT-READING FIELD INSTRUMENTS AND FIXED CONTINUOUS MONITORING DEVICES

Direct-reading field instruments shall be calibrated according to manufacturer's specifications immediately before and after use in the field. In addition, spot checks will be made at reasonable intervals throughout the sampling schedule. Standardization samples shall be obtained from the home laboratory using the appropriate QA procedures inclusive of permanent record keeping and reporting procedures.

Fixed continuous monitoring devices shall be calibrated according to manufacturer's specifications. Wherever possible, results will be verified by approved manual methodology. The calibration of sensors should be checked at least weekly, and preferably on a daily basis. Standardization samples shall be obtained from the home laboratory using the appropriate QA procedures inclusive of permanent record keeping and reporting procedures.

Calibrations and checks of both types of instruments shall always be recorded in logbooks or other permanent records and be reported through established QA channels. Particular care must be exercised where dual-calibrations (both volume and flow) are involved supporting the development of large amounts of data; these conditions shall increase the frequency of required calibration.

III. REPRESENTATIVE SAMPLING AND ADEQUATE SAMPLE SIZE

Assurance of representative sampling, both as to site selection and frequency requires a survey design which provides: (1) a sufficient number of sampling locations; (2) types of samples; (3) frequency of sampling and samples of adequate size (weight or volume). These will provide a valid representation of the characteristics being assessed, and should insure that survey objectives are met.

A Sampling Plan must be prepared by the Project Engineer or Scientist and approved by the Laboratory Manager and the client, before sampling can begin. This plan must be based on accurate process flow diagrams and other process information. It must also clearly specify in detail what is required of the Sampling Engineer or Technician, the needed equipment and supplies, the collection methodology, sample identification and preservation, shipment and storage details and other pertinent data. The Sampling Plan must conform to this QA Standard.

In addition to the above, the development of an effective sampling plan must be based on adequate process information including both production notes and flowrates. Sampling plans must adequately cover hydraulic flow and pollutant loading variations which is usally accomplished by suitable continuous or composite sampling techniques. Flow proportional sampling is essential in all cases other than known steady-state processes.

Adequate sample size is another essential feature. Samples must be large enough to (1) apply the required standard analytical method; (2) to permit the running of duplicate or triplicate analyses should QC or client's needs so require; (3) to permit the preparation of "spiked" or "split" interlaboratory samples should QC, QA, or client's need so dictate; and (4) to permit the retention of one or more "referee" or legal evidence samples should litigation be involved.

Finally, the sample must actually be "representative" of the instantaneous flow stream. This is most easily accomplished by taking the "full stream" for a very short time, by sampling where high turbulent mixing exists (or is caused), or by compositing a group of samples taken at the same time (or under known constant conditions) from an adequately representative number of locations across the cross section of a large channel, stream, pipe, conduit, stack, or process vessel.

Sampling techniques are covered in the following publications.

- Annual Book of ASTM Standards (Part 31), Water, American Society for Testing and Materials, Method D 3370, pp. 71-82, Philadelphia, Pa. July 1975.
- Biological Field and Laboratory Methods for Measuring the Quality of Surface Waters and Effluents, C.I. Weber, Ed., Methods Development and Quality Assurance Research Laboratory, NERC, USEPA Cincinnati, Ohio, July 1973.
- Handbook for Monitoring Industrial Wastewater, Technology Transfer, USEPA, 1973.
- Standard Methods for the Examination of Water and Wastewater (14th Edition), APHA, AWWA, and WPCF, Washington, DC, pp. 38-45, 1975.

IV. COLLECTING, IDENTIFICATION AND PRESERVATION OF SAMPLES

Sample collection, identification, preservation, transportation and storage of samples must all be performed according to accepted and approved procedures designed to insure or to best insure the samples' integrity and the validity of the ultimate analytical results. This is controlled by written procedures which must be respected. When circumstances require or justify deviations from these standard procedures, written approvals must be obtained from the client and retained on file with the particular project as the replacement written authority.

Sample collection shall be carried out using appropriate materials of construction for the sampling equipment and sample containers. Such materials must be chosen to preclude the possibility of both contaminating the sample and the potential for removing or altering in an unacceptable way a pollutant, chemical compound, state of oxidation or reduction, or a parameter of concern. Materials of construction must also be chosen to safely and dependably permit the identification, preservation, transport, and storage of the sample therein contained. Sample containers must also be suitably cleaned prior to use for the same reasons, and may in some special cases be required to be new (never before used) containers.

Sample identification shall be specified in detail in the Sampling Plan which includes the QC program samples as appropriate to the QC Protocol specified by the client. Each container must be premarked with an identification alphanumeric code as a basic minimum. This code will be developed in the Sampling Plan. The Field Sampling Technician or Engineer will enter these codes on the sample in a permanent manner (adequate to survive intact the container use cycle), or the Samplers Log Sheet, and on the Sampling Plan. Both the Samplers Log and the Sampling Plan (field copies) shall be in duplicate; one of each retained by the Sampler and one each packed with the Samples when transported to the Laboratory.

Sampling preservation shall be specified in the Sampling Plan to adequately protect sample validity. This step may involve the introduction of a chemical, such as an acid to solubilize metals require use of refrigeration to protect against progressive chemical reactions or biological activity, or the sealing of full liquid samples (bubble-free) to prevent the introduction or loss of gaseous components. Also included here are sample volume reduction procedures wherein large volume samples are concentrated, extracted or adsorbed in the field to either make handling economic or to protect the sampling validity (prevent escape or introduction of the parameter or potential interference agents).

Sample transportation shall be carried out as specified in the Sampling Plan. This often is a time dependent function, meaning that receipt into the laboratory is time critical. Special transport arrangements should be made in advance, the Sampling Plan adhered to, and the needed personnel deployed to insure rapid sample case handling. Complications and delays occur so that a functional communications plan is often necessary. Sample cases in many instances require refrigeration or freezing temperatures, hence most sample cases are well insulated, but still may require re-icing or dry ice additions en route. These insulated sample cases serve a second function--to help protect samples from loss due to breakage in transit. Where glass containers are required, special packing is essential. Consideraton may be given to using multiple smaller containers for single samples to spread breakage risk. Alternately, critical samples may reasonably be doubled in size and shipped in separate sample cases.

Sample storage takes three basic forms: (1) storage in the field, at or near the sampling site; (2) storage at the base laboratory before and during the analytical and QC procedures; and (3) storage at the base laboratory in a Custodial Sample Storage Room for future litigatory purposes. (This latter grouping will be dealt with in detail later in this program description.) The purpose of field storage is to insure that transported samples arrived at the base laboratory in good condition, for it must be kept in mind that the samples developed under a Sampling Plan are coordinated or temporarily inter-related, and that resampling to cover sample losses (no matter what the cause or causes) is at best an effort that will produce samples of suspect quality.

Sample collection, identification, handling, transportation, and preservation will be performed according to the following documents.

- Manual of Methods for Chemical Analysis of Water and Wastes, EPA-625/6-74-003, U.S. Environmental Protection Agency, Office of Technology Transfer, Washington, DC, 20460, 1974.

- Standard Methods for the Examination of Water and Wastewater, Fourteenth Edition, American Public Health Association, 1975.
- Annual Book of ASTM Standards (Part 31), Water, American Society for Testing and Materials, Method D, 3370 pp. 71-82, Philadelphia, PA, July 1975.
- Biological Field and Laboratory Methods for Measuring the Quality of Surface Waters and Effluents, EPA-670/4-73-001, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio, 45268, July 1973.

Additional methods and procedures may be used as approved or stipulated by the EPA Administrator or Regional Administrator.

A. Time Sensitive Samples

Time-sensitive samples should be delivered from the field and analyzed within specified holding times. Until superseded by designations in published EPA analytical reference methods, maximum holding times for sensitive samples will be as specified in the EPA manuals identified in the previous paragraph.

B. Procedures

Written procedures have been developed to insure sample integrity during sampling, identification, transport, preservation, storage, and analysis.

V. PHYSICAL AND CHEMICAL ANALYSIS

Sample handling, preparation, data keeping, physical and chemical analysis, result calculation and reporting procedures shall conform to the laboratory's adopted "Standard Methods" and shall only be performed by "Certified Analysts" following written procedures established for the specified analytical protocol.

Physical and chemical analysis should be conducted using the analytical methods described in:

- Federal Register, Interim Primary Drinking Water Regulations, Vol. 40, No. 248, Wednesday, December 24, 1975.
- Federal Register, Federal Water Pollution Control Act of 1972 (86 Stat. 816 et. seq. Public Law 92-500 (1972). The Federal Register includes selected methods from the following documents:
  - Standard Methods for the Examination of Water and Wastewater, Fourteenth Edition, American Public Health Association, 1975.
  - Manual of Methods for Chemical Analysis of Water and Wastes, EPA-625/6-74-003, U.S. Environmental Protection Agency, Office of Technology Transfer, Washington, DC, 20460, 1974.
  - 1975 Annual Book of ASTM Standards Part 31, Water, July 1975.

A. Biological Analysis

Biological analysis should be conducted according to the following documents.

(1) Biological Field and Laboratory Methods for Measuring the Quality of Surface Waters and Effluents, EPA-670/4-73-001, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio, 45268, July 1973.

(2) Standard Methods for the Examination of Water and Wastewater, Fourteenth Edition, American Public Health Association, 1975.

B. Alternative Test Procedures

Alternative test procedures can be used provided that the stipulations in the Federal Register statement under "Physical and Chemical Analysis" and as set forth in State statutes and regulations have been satisfied. Analyses conducted on parameters not identified in regulations pursuant to Section 304 (g) Public Law 92-500, should be performed according to generally acceptable methods, unless otherwise specifically required by the Regional Administrator or client.

VI. QUALITY CONTROL AND QUALITY ASSURANCE

All laboratory data collection and analytical programs shall utilize analytical quality control (QC) procedures which conform to one of three established protocols: (1) Protocol I, Precision for Research and Enforcement Purposes; (2) Protocol II, Routine; and (3) Protocol III, Qualitative.

All of the Analytical Protocols will employ accepted QC/QA procedures including combinations of techniques such as: spiked sample recovery, replicate sample analysis, split sample analysis, blind standard sample analysis, and reference sample analysis in manners mutually agreed to by the laboratory and the client. The laboratory is required to routinely document the foregoing control results so that analytical precision and accuracy for each analytical procedure is both known and continuously monitored to immediately trigger suitable corrections should some element of the overall analytical procedure develop a fault.

The operation of this Analytical Laboratory Quality Program conforms to those practices recommended in "Standard Methods for the Examination of Water and Wastewater," 14th Edition, pages 23 through 33, EPEA, AWWA, WPCF, 1975, and any other guidelines, procedures and revisions published by U.S.E.P.A. or any other regulatory agency with pertinent jurisdiction.

A. Qualitative Analysis Protocol III

In the routine process of determining the existence or non-existence of a given or suspected parameter in a specific flow stream, or the determination of the order-of-magnitude concentration of a known-to-be-present parameter in such a stream, and nothing more--a minimum of QC efforts are needed and hence required. This easement is designed to improve the range of laboratory cost-effectiveness, which is ultimately of benefit to the client requiring this type of service.

B. Routine Analyses Protocol II

In the routine analysis of samples, it is assumed that only Standard methods; namely, methods which have been collaboratively studied and found acceptable or methods which have been compared with standard methods and shown to give equivalent precision and accuracy are used.

A standard curve shall be established by running a blank and at least three standards encompassing the full concentration range to be used for routine analysis. Subsequently, every day an analysis is conducted, at least a blank and one standard should be analyzed to verify the original standard curve.

Once the laboratory personnel feel they have mastered the analytical procedures and are ready to begin the routine analysis of samples, the overall precision and accuracy of each procedure in each laboratory and in the hands of each operator using the method should be determined. This will be done by running a known quality control sample (standard concentration) once each day as an unknown sample until a total of at least twenty values are accumulated. These values should be accumulated as part of a day to day or week to week operation and not be obtained all on the same day.

The concentration level chosen to use for the control sample should be at or near the proposed standard for the substance being analyzed. After at least twenty values have been accumulated on the control samples over a period of no less than twenty days, the mean, mean error, standard deviation, and control limits shall be calculated. The data can then either be plotted on a control chart or else posted so that the control limits are available for subsequent use in determining when an analysis is in or out of control.

Once valid precision and accuracy data are available on the method, systematic daily checks shall be run to insure that valid data are being generated. This is accomplished by running at least one control sample every day that an unknown sample is analyzed. If a series of unknown samples are analyzed, run at least one control sample for every twenty unknown samples. The resulting control sample analysis should either be plotted on a control chart or otherwise determined that the result is within the previously calculated control limits. If out of control, analyses of unknowns should be stopped until it can be determined what has gone wrong, and when corrective measures have taken place any samples previously analyzed while out of control should be repeated.

At least once a year and preferably twice a year, an unknown reference sample procured from another laboratory should be analyzed in order to determine that no unforseen difficulties such as erroneously prepared control samples due to poor quality distilled water have occurred.

C. Analyses for Research Enforcement Purposes
Protocol I

The quality control needed for research purposes; namely, the development of new methods and/or the analysis of new types (unusual) of samples, and the quality control needed for enforcement purposes are similar in many respects. In the case of research, the method has not been thoroughly or completely established, and in the case of enforcement, the method is presumably well established and documented but the analyst's ability and his equipment are under suspicion. Hence, both cases require additional checks and controls.

First of all construction and/or verification of the standard curve is necessary. As under routine analysis, the standard curve is established by running a blank and at least three standards encompassing the full concentration range of the analysis. In addition, however, at the completion of the analysis of one or a series of samples, at least one blank and one standard shall be analyzed to verify that conditions have not changed.

In order to document that reproducible results are being obtained on an unknown sample, triplicate analyses shall be run on all samples. The resulting data must agree favorably with the known precision of the method (enforcement) or of the precision of similar methods of analysis for the same substance (research).

In order to account for background contamination and/or interferences in the sample, each sample should be spiked with a standard solution at, at least, three different concentrations (high, low, and intermediate). Again, the resulting data should agree with itself (similar recovery at each concentration) and with the known accuracy of the method or of other similar methods.

In addition to running standards, and in order to establish their accuracy, a reference sample obtained from some outside source such as the National Bureau of Standards, and if possible certified as to its accuracy, should be run at the same time; (namely, part of the same series) as the standards and unkonwns discussed above are run.

Any laboratory analyses performed for the primary purpose of providing data for a litigation procedure should have the primary standard (for each parameter involved) certified and notarized by at least one independent laboratory of recognizable qualifications. This certification of standard should be in letter form, suitable for being submitted as evidence.

D. Laboratory Review Requirements

The States, contractors, grantees, and other parties involved in compliance monitoring shall make their monitoring support laboratories, laboratory data records, and records indicating laboratory techniques used, open to EPA review as required by the Regional Administrator.

An official document entitled "Criteria and Procedures for the Certification of Water Supply Laboratories" developed by the Water Supply Quality Assurance Work Group of EPA, is available as a guide. Reference should also be made to the several laboratory survey documents developed by the Environmental Monitoring and Support Laboratory, EPA-Cincinnati, for use of Regional Coordinators with State agencies. The documents include guidelines for evaluating:

- Sampling Techniques
- Preservation Techniques
- Analytical Methodology
- Data Handling
- Quality Control
- Personnel
- Space and Services
- Equipment

Any client for laboratory services shall have the same review privileges unless a proprietary process, piece of equipment, or method is in use in which case this exclusion shall be made known to the client before the service is undertaken.

E. Special Cases

1. Instrumental Field Measurements

All instruments used in field measurements, such as temperature, dissolved oxygen, conductivity, pH, probe measurements (fluoride, ammonia), flow measurements, etc., must be calibrated against approved analytical procedures or known standards at the beginning of the day's sampling run and must be checked at the end of the same day to determine any changes in performance.

These calibrations and check data shall be recorded in either a laboratory or field book for future reference.

2. Unusual Samples

Single grab samples that can't be subdivided, such as those collected for oil and grease analyses, must be taken in replicate, one after another in a minimum time frame from the same sampling point, in order to provide adequate samples for subsequent laboratory analysis and quality control.

In those cases where a one-day average is required and a sample cannot be composited, such as for oil and grease or time dependent determinations, individual grab samples must be collected within prescribed time intervals (depending on the sampling situation), analyzed individually, and their average values calculated. In such situations, minimum and maximum values should also be reported. For quality control purposes, at least one and, perferably, two of the grab samples should be taken in triplicate so that precision and accuracy checks can be made and recorded.

3. Samples Exceeding Upper Concentration Limits

If laboratory analysis for a particular constituent shows that its calculated value exceeds the upper limit of the working range of the method or indicates that a violation has been observed, the analyst shall re-run the suspected sample at two different dilution levels in order to verify initial results.

4. Samples Containing Concentrations Below Minimum Detection Limits

If a laboratory analysis for a particular constituent is suspected of existing below the lower limit of the working range of the method and the analyst is under instruction to pursue that parameter's value, the analyst will select and attempt to use a suitable concentration or extraction technique in parallel to a control concentrative or extractive process employing known concentrations to establish a concentrative process efficiency for use in data workup.

F. Recording, Storing, and Retrieving Data

Contractor/grantee and laboratory personnel must keep complete and permanent records to satisfy legal requirements for potential enforcement or judicial proceedings. The Sampling Technician or Engineer must sign the field sheets, and the Analyst must sign the laboratory data sheets. In addition, an information system should be developed which can prepare, screen, validate, sort, display and make wastewater data collected by contractors/grantees available to EPA or other clients.

VII. CHAIN OF CUSTODY PROCEDURES

The following procedures have been used successfully, and are presented as suggested procedures insofar as they fulfill the legal requirements of the appropriate State legal authority. It should be noted, however, that not all samples need to be handled in the manner described below. Only those which are suspected or previously found to contain a significant amount of a pollutant and/or exceeding a legal standard and, therefore, presumably subject to involvement in a legal action must be handled by the COC (Chain of Custody) procedures. It is recognized, for example, that many and in some cases, nearly all of the samples going through a laboratory are of a surveillance or routine monitoring type and many contain nothing of importance. To require all such samples to be subjected to the "chain of custody" would be extremely costly, time consuming and of no practical value.

A. Procedures (COC)

Quality assurance must be stressed during all compliance monitoring and when reviewing self-monitoring programs, no matter what the reason for the spot check or inspection. Successful implementation of a compliance monitoring program depends heavily on the capability to produce valid data, and on clearly demonstrating such validity. No other environmental monitoring area requires more rigorous adherence to validated methodology and quality control measures.

It is imperative that laboratories and field operations involved in collecting primary evidence prepare written procedures. These procedures shall be used whenever evidence samples are collected, transferred, stored, analyzed, or destroyed. A primary objective of these procedures is to insure the preparation of accurate written record which can be used to trace possession of the sample from the time it is collected through its introduction into evidence.

B. Preparing Samples (COC)

The evidence-gathering portion of a survey is characterized by an absolute minimum number of samples required to give a fair representation of the effluent or water body sampled. The quantity and location of samples are determined before the survey and shall be shown in the client approved Sampling Plan.

Prepare chain-of-custody record tags before actual field survey work. Insure tags contain all possible information to minimize clerical work by field personnel. Also write the source of each sample on the container before starting any field survey work. Field logsheets used to document field procedures and chain-of-custody and to identify samples, should be prefilled to the extent practicable to reduce repetitive clerical field entries. The Sampling Technician or Engineer or project leader should maintain custody during sampling, using the logbook. Any information from previous studies must be copied (or removed) and filed before the log book is returned to the field. Follow explicit chain-of-custody procedures to maintain the documentation necessary to trace sample possession from the time the sample is taken until the evidence is introduced into court. A sample is in your custody if:

- It is in your physical possession; or
- It is in your view, after being in your physical possession; or
- It was in your physical possession and you locked it in a transfer-proof container or storage area.

All survey participants shall receive a copy of the study plan and should be familiar with its contents before the survey begins. A pre-survey briefing must be held to inform all participants of the survey objectives, sample locations and chain-of-custody procedures. After all chain-of-custody samples are collected, a debriefing shall be held in the field to verify that chain-of-custody procedures have been followed, and to determine if additional evidence samples are required. These meetings, their content and attendees shall be entered into the permanent record.

C. Collecting Samples (COC)

Insure that the smallest possible number of people handle the sample.

Obtain stream and effluent samples using standard field sampling techniques. When using sampling equipment, assume it is in the custody of the source being sampled.

Attach chain-of-custody record tag to the sample container when the complete sample is collected. Insure the container has the following information: sample number, time taken, date taken, source of sample (include type of sample and name of firm), preservative, analyses required, name of person taking sample, and witnesses. The front side of the card (which has been prefilled) is signed, timed, and dated by the person doing the sampling. Tags must be legible and filled out in ballpoint (water-proof ink). Secure individual sample containers or group of sample containers using a tamper-proof seal.

Blank samples shall be prepared by adding distilled water to two containers of the same type as used to collect the test sample. To one container add preservative. Leave the other unpreserved. The laboratory will analyze both to exclude the possibility of container and/or preservative contamination.

Maintain an up-to-date bound Field Data Record Logbook. Record field measurements and other pertinent information necessary to refresh the sampler's memory if, later on, he takes the stand to testify regarding his actions during the evidence-gathering activity. Maintain a separate set of field notebooks for each survey; store them in a safe place where they can be protected and accounted for at all times.

Standard formats have been established to minimize field entries: these include the data, time, survey, type of samples taken, volume of each sample, type of analysis, sample numbers, preservatives, sample location and field measurements (temperature, conductivity, DO, pH, flow), and any other pertinent information or observations.

The field sampler (Sampling Technician or Engineer) signs the entries. The survey coordinator is usually responsible for preparing and conserving the field logbook during the survey. Once the survey is complete, field logs will be retained by the survey coordinator or his designated representative, as a part of the permanent record.

The field sampler is responsible for the care and custody of the collected samples until they are properly dispatched to the receiving laboratory, or turned over to an assigned custodian. The field sampler should verify that each container is in his physical possession or in his sight at all times, or is locked so that no one can tamper with it.

Colored slides or photographs shall be taken to show the outfall sample location and any visible water pollution. Written documentation on the back of the photo should include the photographer's signature, time, date, and site location. These photographs can be used as evidence, and are handled by chain-of-custody procedures to prevent alteration.

D. Transfer of Custody and Shipment (COC)

When transferring the possession of samples, the transferee signs, dates, and times the reverse side of the chain-of-custody record tag or record. Custody transfers, if made to a sample custodian in the field, are made for individual samples. The chain-of-custody tag or card must be dated and signed by the second person who takes custody. If a third person takes custody, he must follow the same procedure. An additional chain-of-custody tag or card is completed by persons who thereafter, take custody. It is apparent, from this chain, that the number of custodians should be minimal. Additional tags or cards should be numbered consecutively.

If a field custodian has not been assigned, the field sampler is usually responsible for properly packaging and dispatching samples to the proper laboratory for analysis. In that case, the "Dispatch of Sample" portion of the chain-of-custody record tag or card should be properly filled out, dated, and signed.

Insure that samples are properly packed in shipping containers (for example, ice chests) to avoid breakage. Insure that shipping containers are padlocked for shipment to the receiving laboratory.

Include a "Sample Transmittal Sheet" with all packages. The original and one copy generally accompany the shipment. If package is hand-delivered, record delivery in the logbook. Send receipts from post offices and bills of lading to the laboratory custodians for retention as part of the permanent chain-of-custody documentation.

When samples are delivered to the laboratory, and appropriate personnel are not there to receive them, samples should be locked in a secure, tamper-proof area. The same person must unlock the samples and deliver custody to the appropriate custodian.

E. Laboratory Custody Procedures (COC)

The following procedures are recommended by the EPA's National Enforcement Investigation Center, and are suggested to the State insofar as they comply with the State's statutory and regulatory requirements.

The laboratory director will designate one full-time employee as a sample custodian, and one other person as an alternate. In addition, the laboratory must provide a sample storage area that is secure. This is a clean, dry, isolated room which can be securely locked.

All samples will be handled by a minimum possible number of persons.

Only the custodian will receive incoming samples. If he is absent, the alternate will indicate receipt by signing the sample transmittal sheets and (as appropriate), the sample tags which accompany the samples. The alternate will retain the transmittal sheets as permanent records.

Immediately upon receipt, the custodian will place the sample in the sample room, which will be locked at all times execpt when the samples are removed or replaced by the custodian. To the maximum extent possible, only the custodian should be permitted in the sample room.

The custodian shall insure that heat-sensitive or light-sensitive samples, or other sample materials having unusual physical characteristics, or requiring special handing, are properly stored and maintained.

Only the custodian will distribute samples to personnel who are to perform tests.

The analyst will record in his laboratory notebook or analytical worksheet, identifying information describing the sample, the procedures performed and the results of the testing. The notes shall be retained as a permanent record in the laboratory and should note any abnormalities which occurred during the testing procedure. In the event that the person who performed the tests is not available as a witness at time of trial, the government may be able to introduce the notes in evidence under the Federal Business Records Act.

Standard methods of laboratory analyses shall be used as described in the "Guidelines Establishing Test Procedures for Analysis of Pollutants," 38 F.R. 28758, October 16, 1973. If laboratory personnel deviate from standard procedures, they should be prepared to justify their decision during cross-examination.

Laboratory personnel are responsible for the care and custody of the sample once it is handed over to them and should be prepared to testify that the sample was in their possession and view or secured in the laboratory at all times from the moment it was received from the custodian until the tests were run.

F. Sample Disposition (COC)

Once the sample testing has been completed, the unused portion of the sample, together with all identifying tags and laboratory records, should be returned to the custodian. The returned tagged sample will be retained in the sample room until it is required for trial. Strip charts and other documentation of work will also be turned over the the custodian.

Samples, tags and laboratory records of tests may be destroyed only upon the order of the laboratory director, who will first confer with the Chief, Enforcement Specialist Office, to make certain that the information is no longer required.

VIII. SAMPLE CONTRACT AND GRANT PROVISION FOR QUALITY ASSURANCE

Any laboratory analyses performed in support of this project shall use EPA methods whenever possible. The ability of the supporting laboratory to provide reliable data shall be demonstrated by satisfactory performance on reference samples provided to the grantee by the EPA's Environmental Monitoring and Support Laboratory, Quality Assurance Branch, Cincinnati, Ohio. Internal laboratory control shall conform to practices recommended by the EPA and/or as required by the Project Officer.

IX. REFERENCES

Sampling

1. Annual Book of Standards (Part 23), Water and Atmospheric Analysis, American Society for Testing and Materials, Method D 1496 510, pp. 72-91, Philadelphia, PA, 1973.

2. Biological Field and Laboratory Methods for Measuring the Quality of Surface Waters and Effluents, C.I. Weber, Ed., Methods Development and Quality Assurance Research Laboratory, NERC, USEPA, Cincinnati, Ohio, July 1973.

3. Donahue, A., Sample Handling - Field Through Laboratory, National Training Center, Outline WP. SUR. Sq. June 12, 1971, NERC, USEPA, Cincinnati, Ohio, June 1971.

4. Handbook for Monitoring Industrial Wastewater, Technology Transfer, USEPA, 1973.

5. Standard Methods for the Examination of Water and Wastewater (14th Edition), APHA, AWWA, and WPCF, Washington, DC, pp. 38-45, 1975.

Preservation and Holding Times

6. Methods for Chemical Analysis of Water and Wastes, MDQARL, NERC, USEPA, Cincinnati, Ohio, September 1971.

7. Op. Cit., Reference 5.

Laboratory Analyses

8. Federal Register, Vol. 38, No. 199, Part II, Guidelines Establishing Test Procedures for Analysis of Pollutants, pp. 28758-28760, October 16, 1973.

9. Op. Cit., Reference 6.

10. Op. Cit., Reference 5.

11. Op. Cit., Reference 4 (Approved Methods Only).

12. Op. Cit., Reference 3 (Approved Methods Only).

13. Ocean Dumping Methods Manual (For Site Monitoring and Sludge Analysis).

14. Federal Register, Interim Primary Drinking Water Regulations, Vol. 40, No. 248, Part IV, Wednesday, December 24, 1975.

Laboratory Quality Control

15. Handbook for Analytical Quality Control in Water and Wastewater Laboratories, MDQARL, NERC, USEPA, Cincinnati, Ohio, June 1972.

16. Industrial Hygiene Service Laboratory Quality Control Manual, Technical Report No. 78, DREW, PHS, NIOSH, Cincinnati, Ohio, March 1973.

17. Standard Methods for the Examination of Water and Wastewater, Fourteenth Edition, Pages 26 through 33, APEA, AWWA, WPCF, 1975.

18. Guidelines Establishing Test Procedures for Analysis of Pollutants, 40 CRF Park 136, U.S. Environmental Protection Agency, Quality Assurance Division, Washington, DC, Number 199, pp. 28758-28760, October 16, 1973.

19. Proceedings of the First Microbiology Seminar on Standardization of Methods, U.S. Environmental Protection Agency, Quality Assurance Division, Washington, DC, Reprot No. EPA-R4-73-002, March 1973.

APPENDIX F - FORTRAN CODE FOR WATER QUALITY DATA CHECKING PROGRAM

```
      PROGRAM WQED(INPUT,OUTPUT,TAPE7=/160,TAPE5=INPUT,TAPE6=OUTPUT)
C
C  THIS PROGRAM CHECKS THE WQ DATA
C
      REAL NA,MG,NO3,K
      INTEGER D1,D2,Y1,Y2
      COMMON WELLNO(2),REM(6),NA,CA,MG,SO4,HCO3,B,TDS,TOC,NO3,H,
     1K,CL,U,TH
C
C WRITE HEADING
      WRITE(6,1003)
      KK=0
    1 READ(5,1001)WELLNO,M1,D1,Y1,M2,D2,Y2,NA,CA,MG,SO4,HCO3,B,TDS,
     1TOC,NO3,H,K,CL,UX,U,THX,TH,REM
      IF(EOF(5))5,10
   10 KK=KK+1
 1001 FORMAT(A10,A3,I2,2(1X,I2),I2,2(1X,I2),F6.1,F5.1,F5.1,2F6.1,
     1F6.2,F7.0,F5.2,F4.1/2F6.1,F5.1,A1,F3.0,A1,F4.0,5A10,A4)
C
C  CHECK FOR ERRORS IN DATE
C
      IF(M1 .GT. 12 .OR. M2 .GT. 12)WRITE(6,1002)KK,WELLNO,M1,D1,Y1,M2
     1,D2,Y2
      IF(D1 .GT. 31 .OR. D2 .GT. 31)WRITE(6,1002)KK,WELLNO,M1,D1,Y1,M2
     1,D2,Y2
 1002 FORMAT(/1X,I5,5X,A10,A3,6I8)
      WRITE(6,1004)WELLNO,NA,CA,MG,SO4,HCO3,B,TDS,TOC,NO3,H,
     1K,CL,UX,U,THX,TH
 1004 FORMAT(///2X,A10,A3,3X,5F8.1,F8.2,F8.0,F8.2,4F8.1,3X,A1,F4.0,2X,
     1A1,F5.0)
C
C  CALL CHECKING SUBROUTINES
C
      CALL CALTDS
      CALL TDS1
      CALL HARD
      CALL CATAN
C
      INA=NA*10.
      ICA=CA*10.
      IMG=MG*10.
      ISO4=SO4*10.
      IHCO3=HCO3*10.
      IB=B*100.
      ITDS=TDS
      INO3=NO3*10.
      IH=H*10.
      IK=K*10.
      ICL=CL*10.
      ITOC=TOC*100.
      IU=U
      ITH=TH
C
C
      WRITE(7,1005)WELLNO,M1,D1,Y1,M2,D2,Y2,INA,ICA,IMG,ISO4,
     1IHCO3,IB,ITDS,ITOC,INO3,IH,IK,ICL,UX,IU,THX,ITH,REM
 1005 FORMAT(A10,A3,I2.2,2(1H/,I2.2),I2.2,2(1H/,I2.2),I6.6,
                1215.5,316.6,17.7,15.5,14.4,216.6,15.5,A1,13.3,A1,14.4,5A10,A4)
                 GO TO 1
 60            5 STOP
            1003 FORMAT(1H1,/15X,*  WATER QUALITY DATA  *//3X,* WELL NO *,
                110X,* NA *,4X,* CA *,4X,* MG *,3X,* SO4 *,2X,* HCO3 *,
                25X,* B *,3X,* TDS *,3X,* TOC *,3X,* NO3  HARDNESS     K *,
                34X,* CL *,5X,* U *,4X,* TH *)
 65              END

CARD NR. SEVERITY  DETAILS   DIAGNOSIS OF PROBLEM

  57      I      68 CD 58  TOTAL RECORD LENGTH IS GREATER THAN 137 CHARACTERS.  IT MAY EXCEED THE I/O DEVICE CAPACITY.
```

```
      SUBROUTINE CALTDS
C
C  THIS SUBROUTINE CALCULATES THE TOTAL DISSOLVED SOLIDS BY
C   ADDING UP THE AVAILABLE COMPONENTS
C
      REAL NA,MG,NO3,K
      COMMON WELLNO(2),REM(6),NA,CA,MG,SO4,HCO3,B,TDS,TOC,NO3,H,
     1K,CL,U,TH
C
      CALC=NA+CA+MG+SO4+HCO3+B+TOC+((62./14.)*NO3)+K+CL
      IF(NA .GE. 99999.9)GO TO 5
      IF(CA .GE. 9999.9)GO TO 5
      IF(MG .GE. 9999.9)GO TO 5
      IF(SO4 .GE. 99999.9)GO TO 5
      IF(HCO3 .GE. 99999.9)GO TO 5
      IF(B .GE. 9999.99)CALC=CALC-9999.99
      IF(TOC .GE. 999.99)CALC=CALC-999.99
      IF(NO3 .GE. 999.9)CALC=CALC-3713.91
      IF(K .GE. 99999.9)GO TO 5
      IF(CL .GE. 9999.9)GO TO 5
      WRITE(6,1001)CALC
 1001 FORMAT(/5X,* CALCULATED SUM OF CONSTITUENTS=*,F10.0)
    5 RETURN
      END
      SUBROUTINE HARD
C
C THIS SUBROUTINE COMPUTES THE HARDNESS AS THE SUM OF THE
C   CA AND MG CONCENTRATIONS
C
      REAL NA,MG,NO3,K
      COMMON WELLNO(2),REM(6),NA,CA,MG,SO4,HCO3,B,TDS,TOC,NO3,
     1H,K,CL,U,TH
C
      CALC=CA*2.497+MG*4.116
      IF(H .LE. 0.0)GO TO 12
      IF(CA .GE. 9999.9 .OR. MG .GE. 9999.9)GO TO 15
      ERROR=((CALC-H)/H)*100.
      WRITE(6,1001)CALC,H,ERROR
 1001 FORMAT(5X,* CALCULATED HARDNESS= *,F8.1,*  HARDNESS= *,
     1F8.1,*    PERCENT ERROR= *,F8.2)
      RETURN
   12 WRITE(6,1002)
 1002 FORMAT(5X,* HARDNESS EQUALS 0 *)
   15 RETURN
      END
      SUBROUTINE CATAN
C
C  THIS SUBROUTINE COMPUTES THE CATION-ANION BALANCE
C   AND CHECKS IF IT IS WITHIN ACCEPTABLE LIMITS,I.E.
C    ONE STANDARD DEVIATION
C
C   CATIONS-NA,CA,MG,K
C   ANIONS-SO4,HCO3,NO3,CL
C
      REAL NA,MG,NO3,K
      COMMON WELLNO(2),REM(6),NA,CA,MG,SO4,HCO3,B,TDS,TOC,NO3,
     1H,K,CL,U,TH
C
      CAT=(NA/22.9898)+(CA/20.04)+(MG/12.156)+(K/39.102)
      IF(NA .GE. 99999.9)GO TO 15
      IF(CA .GE. 9999.9)GO TO 15
      IF(MG .GE. 9999.9)GO TO 15
      IF(K .GE. 99999.9)GO TO 15
      ANION=(SO4/48.032)+(HCO3/61.0)+(NO3/14.)+(CL/35.453)
      IF(SO4 .GE. 99999.9)GO TO 15
      IF(HCO3 .GE. 99999.9)GO TO 15
      IF(NO3 .GE. 999.9)GO TO 15
      IF(CL .GE. 9999.9)GO TO 15
      DELTA=CAT-ANION
      STDV=0.0165+0.0155*ANION
      WRITE(6,1001)CAT,ANION,DELTA
 1001 FORMAT(/5X,* CATIONS= *,F8.1,* ME/L   ANIONS= *,
     1F8.1,* ME/L  DIFFERANCE= *,F6.1)
      IF(ABS(DELTA) .GT. STDV .AND. ABS(DELTA) .GT. 1.0)
     1WRITE(6,1002)STDV
 1002 FORMAT(5X,*  CATION-ANION BALANCE IN ERROR, DIFFERANCE*,
     1* GREATER THAN ST. DEV. OF *,F5.1/)
   15 RETURN
      END
      SUBROUTINE TDS1
C
C  THIS SUBROUTINE COMPUTES TOTAL DISSOLVED SOLIDS INCLUDING
C   THE WATERS OF CRYSTALLIZATION
C
C    IT SHOULD BE USED TO COMPARE COMPLETE WATER ANALYSES WITH
C     TOTAL DISSOLVED RESIDUE AT 103-110 DEGREES CELSIUS
C
C    BASED ON       SOKOLOFF,V.P., 'WATER OF CRYSTALLIZATION IN
C                   TOTAL SOLIDS OF WATER ANALYSES', INDUSTRIAL
C                   AND ENGINEERING CHEMISTRY,ANALYTICAL EDITION,
C                   VOLUME 5,P. 336, NOVEMBER 1933
C
      REAL NA,MG,NO3,K,NAX,MGX,NO3X,KX,NACLX,KCLX,NASO4X,
     1KSO4X,MGSO4X,MGCO3X,MGCLX,MGNO3X,NANO3X,KNO3X,NACO3X,
     2KCO3X
      COMMON WELLNO(2),REM(6),NA,CA,MG,SO4,HCO3,B,TDS,TOC,NO3,H,K,CL,
     1U,TH
C
C  IF IMPORTANT PARAMETERS ARE MISSING-  RETURN
C
      IF(NA .GE. 99999.9)GO TO 5004
      IF(CA .GE. 9999.9)GO TO 5004
      IF(MG .GE. 9999.9)GO TO 5004
      IF(K .GE. 99999.9)GO TO 5004
      IF(SO4 .GE. 99999.9)GO TO 5004
      IF(HCO3 .GE. 99999.9)GO TO 5004
      IF(CL .GE. 9999.9)GO TO 5004
C
C  CONVERT TO MILLIEQUIVALENTS
C
      NAX=NA/22.9898
      CAX=CA/20.04
      MGX=MG/12.156
      KX=K/39.102
      SO4X=SO4/48.032
      CLX=CL/35.453
      HCO3X=HCO3/61.
      NO3X=NO3/14.
C
C  STEP 1     CA + 2HCO3 = CACO3 + H2O + CO2
C
      CACO3X=AMIN1(CAX,HCO3X)
      CAX=CAX-CACO3X
      HCO3X=HCO3X-CACO3X
C
C  STEP 2  MG + 2HCO3 = .75(MGCO3) + .25(MG(OH)2) +.75(H2O)
C
      MGCO3X=AMIN1(MGX,HCO3X)
      MGX=MGX-MGCO3X
      HCO3X=HCO3X-MGCO3X
C
C  STEP 3  CA + SO4 =CASO4 + .5(H2O)
C
      CASO4X=AMIN1(CAX,SO4X)
```

```
C
C  STEP 4 NA + CL = NACL
C
      NACLX=AMIN1(NAX,CLX)
      NAX=NAX-NACLX
      CLX=CLX-NACLX
      KCLX=AMIN1(KX,CLX)
      KX=KX-KCLX
      CLX=CLX-KCLX
C
C  STEP 5   2NA + SO4 = (NA)2SO4
C
      NASO4X=AMIN1(NAX,SO4X)
      NAX=NAX-NASO4X
      SO4X=SO4X-NASO4X
      KSO4X=AMIN1(KX,SO4X)
      KX=KX-KSO4X
      SO4X=SO4X-KSO4X
C
C STEP 6    MG + SO4 = MGSO4 * H2O
C
      MGSO4X=AMIN1(MGX,SO4X)
      MGX=MGX-MGSO4X
      SO4X=SO4X-MGSO4X
C
C STEP 7   MG + 2CL = MG(CL)2 * 6H2O
C
      MGCLX=AMIN1(MGX,CLX)
      MGX=MGX-MGCLX
      SO4X=SO4X-MGCLX
C
C STEP 8   2NA + 2HCO3 = (NA)2CO3 * H2O
C          2K + 2HCO3 = (K)2CO3 *2H2O
C
      NACO3X=AMIN1(NAX,HCO3X)
      NAX=NAX-NACO3X
      HCO3X=HCO3X-NACO3X
      KCO3X=AMIN1(KX,HCO3X)
      KX=KX-KCO3X
      HCO3X=HCO3X-KCO3X
C
C  STEP 9  CA + 2CL = CA(CL)2 * 2H2O
C
      CACLX=AMIN1(CAX,CLX)
      CAX=CAX-CACLX
      CLX=CLX-CACLX
C
C  STEP 10    NA + NO3 = NANO3
C
      NANO3X=AMIN1(NAX,NO3X)
      NAX=NAX-NANO3X
      NO3X=NO3X-NANO3X
      KNO3X=AMIN1(KX,NO3X)
      KX=KX-KNO3X
      NO3X=NO3X-KNO3X
C
C  STEP 11    CA + 2NO3 = CA(NO3)2 * 4H2O
C
```

```
      CANO3X=AMIN1(CAX,NO3X)
      CAX=CAX-CANO3X
      NO3X=NO3X-CANO3X
C
C  STEP 12  MG + 2NO3 = MG(NO3)2 * 6H2O
C
      MGNO3X=AMIN1(MGX,NO3X)
      MGX=MGX-MGNO3X
      NO3X=NO3X-MGNO3X
C
C  CALCULATION OF THEORETICAL TOTAL DISSOLVED SOLIDS
C     AT 103-110 DEGREES CELSIUS
C
      ETDS=(CACO3X*50.02)+(MGCO3X*43.531)+(CASO4X*72.556)+
     1(NACLX*58.443)+(KCLX*74.555)+(NASO4X*71.022)+
     2(KSO4X*87.134)+(MGSO4X*69.188)+(MGCLX*101.609)+
     3(NACO3X*62.0)+(KCO3X*87.102)+(CACLX*73.493)+
     4(NANO3X*85.0)+(KNO3X*101.1)+(CANO3X*118.04)+
     5(MGNO3X*128.156)
C
C  ADD UNACCOUNTED-FOR IONS
C
      ETDS=ETDS+(NAX*22.9898)+(CAX*20.04)+(MGX*12.156)+
     1(KX*39.102)+(SO4X*48.032)+(CLX*35.453)+(NO3X*62.)
C  ADD REMAINING COMPONENTS
C
      IF(B .GE. 9999.99 .OR. TOC .GE. 999.99)GO TO 54
      ETDS=ETDS+B+TOC
   54 CONTINUE
C COMPUTE ERROE
      ERROR=((ETDS-TDS)/TDS)*100.
      WRITE(6,1001)ETDS,TDS,ERROR
 1001 FORMAT(/5X,*CALCULATED TDS= *,F10.0,*  TDS= *,F10.0,
     1*    PERCENT ERROR=  *,F8.2/)
 5004 RETURN
      END
```

APPENDIX G

AQUIFER TEST ANALYSIS TECHNIQUES

After a single well or multiwell aquifer test, the data collected (usually time and drawdown) has to be analyzed to give the aquifer characteristics of transmissivity (T), and hydraulic conductivity (K) and storage coefficient. The selection of proper analysis method is determined by the type of test that has been performed, the type of aquifer tested, and the local and regional geology of the area where the aquifer is located. The analysis methods outlined here are by no means complete. They are, however, the ones that Hittman Associates has found, through extensive aquifer testing and experience, to be the ones that are used most frequently.

With the exception of the Cooper-Jacob method of analysis, all methods for pumping tests require that the time-drawdown data collected during the test be plotted on logarithmic paper. The resulting data plot is then overlain on the appropriate type curve plotted on the same size of graph paper. The horizontal and vertical axes are kept parallel. The field data plot is moved until the best fit is obtained. A match point is selected and the values of time (t), drawdown (s), the value from the vertical type curve axis and the value from the horizontal type curve axis for the selected point are determined. These values are then used to determine the transmissivity and storage coefficient of the aquifer. Hydraulic conductivity is calculated by dividing the transmissivity by the aquifer thickness. The analysis of "slug" test data is similar to that outlined with the exception that a semilogarithmic plot is made of time, and the quotient of the residual water level is divided by the initial water level. No type curve fitting is necessary for the Cooper-Jacob method. For further information on aquifer testing methods and analysis, see References 9 and 10.

A. Nonsteady Radial Flow Without Vertical Movement

1. Constant Discharge

a. Theis Method. In 1935, C.V. Theis developed the first valid equation for nonsteady flow to a fully penetrating, pumped well in a homogeneous, isotropic, confined aquifer. The basic equation is

$$s = \frac{114.6Q}{T} W(u) \qquad \text{(G-1)}$$

where

$$u = \frac{1.87r^2 S}{Tt} \qquad \text{(G-2)}$$

$$W(u) = \int_u^\infty \frac{e^{-u}}{u} \, du \qquad \text{(G-3)}$$

s = drawdown

r = distance from pumped well to the observation point, in feet

Q = discharge in gallons per minute (gpm)

t = time after pumping started

T = transmissivity, in gallons per day per foot

S = coefficient of storage, dimensionless

Equation G-1 is solved by using the type curve method previously outlined. The plot of s vs. t is fit over a plot of W(u) vs. 1/u (Figure G-1) and values for s, t, u, and W(u) are determined for the match point. Transmissivity is solved for by substituting W(u), s, and Q into Equation G-1 and solving for T. Storage coefficient is solved for by substituting the calculated T, r, t, and u into Equation G-2 and solving for S.

b. Cooper-Jacob Method. Cooper and Jacob showed that for values of u = .01 Equation G-3 can be closely approximated by

$$W(u) = -.577216 - \ln \frac{r^2 S}{4Tt} \qquad \text{(G-4)}$$

Equation G-1 then can be reduced to

$$s = \frac{264Q}{T} \log \frac{t_2}{t_1} \qquad \text{(G-5)}$$

For a full log cycle $\log \frac{t_2}{t_1} = 1$ and

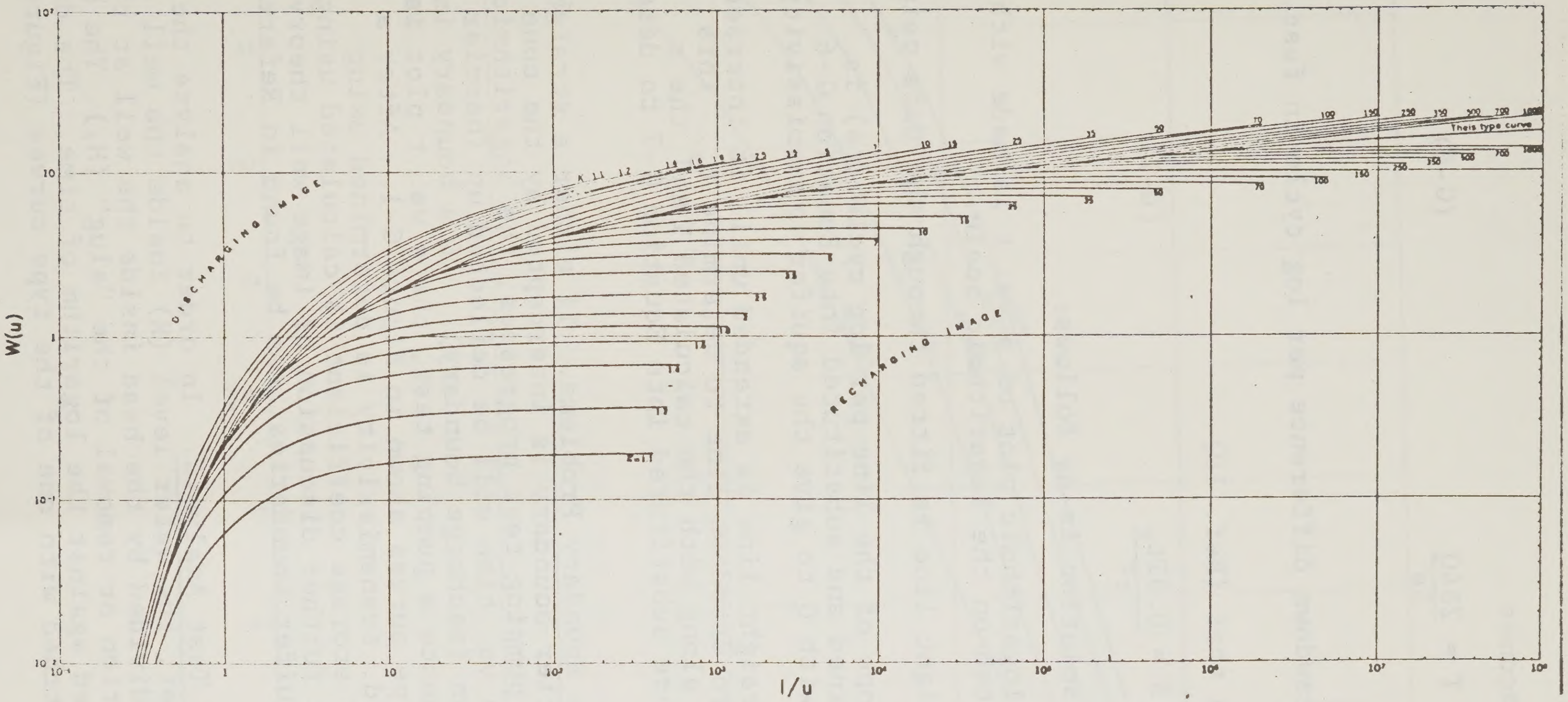


Figure G-1. Logarithmic Plot of W(u) Versus 1/U for Image Wells

Equation G-5 becomes

$$T = \frac{264Q}{\Delta s} \qquad (G\text{-}6)$$

where

Δs = drawdown difference per log cycle in feet.

It can be shown that (Ref. 10)

$$S = \frac{0.3Tt_0}{r^2} \qquad (G\text{-}7)$$

The method for solution is as follows:

1) A semilogarithmic plot of s vs. t is made with t plotted on the logarithmic scale.

2) A straight line is fitted through the data points.

3) The slope of the line per log cycle (Δs) is determined and substituted into Equation G-6 along with Q to give the aquifer transmissivity.

4) The straight line is extended until it intersects the zero drawdown line to determine t_0. This value, along with the calculated T and the r value are substituted into Equation G-7 to determine S.

c. Single Boundary Problems. If either a straight, recharge or barrier boundary is intercepted by the cone of depression as a pumping test progresses, the logarithmic plot of drawdown vs. time will be deflected up (barrier boundary) or down (recharge boundary). If a boundary is thought to influence a pumping test, the s vs. t plot is fit to one of the type curves shown in Figure G-1. After a match point is selected, transmissivity is determined using Equation G-1 and storage coefficient is calculated using Equation G-2. A further discussion of image well theory, as applied to aquifer boundaries, can be found in Reference 9.

d. "Slug" Test Analysis. In order to analyze the data from a "slug" test, the water level (H) inside the well at time t is first divided by the head inside the well at the instant of injection or removal of the "slug" (H_0). The H/H_0 values are plotted against the logarithm of time. The data curve is then matched with one of the type curves (Figure G-2).

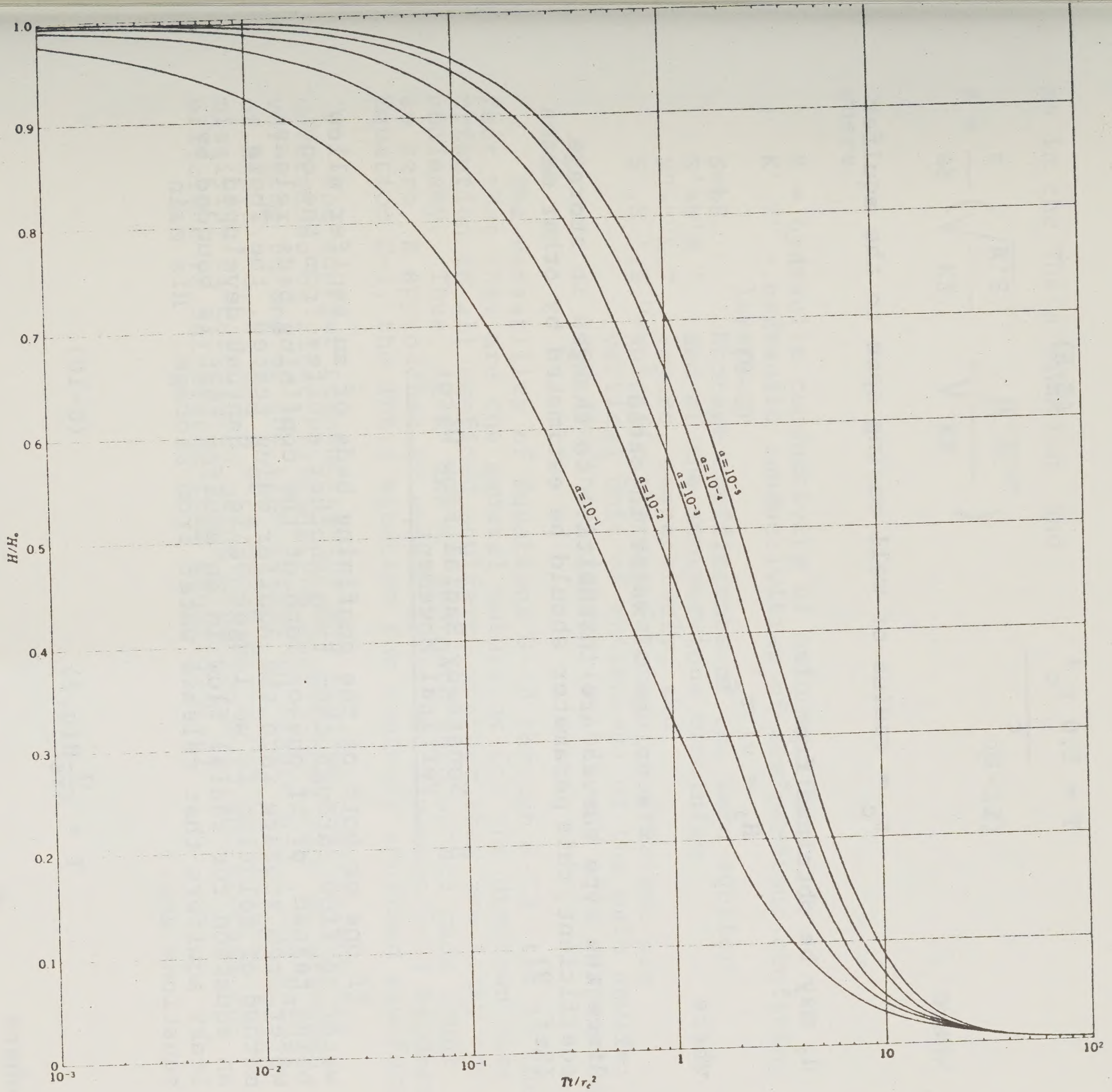


Figure G-2. Type Curves for H/H_0 Versus Tf/r_c^2 for Five Values of a

The value of t when $Tt/r_c^2 = 1.0$ is determined. Transmissivity is given by:

$$T = \frac{1.0\, r_c^2}{t} \qquad \text{(G-8)}$$

where

r_c = radius of well casing open to the aquifer

H_0 may be obtained from:

$$H_0 = \nu/\pi r_c^2 \qquad \text{(G-9)}$$

where

ν = volume of water injected.

Since the type curves are insensitive to changes in storage coefficient, this parameter should be estimated by other means (Ref. 9).

B. Nonsteady Radial Flow With Vertical Movement

If one or both of the confining beds of an aquifer allow water to flow through them from another aquifer from the one being tested, or if one or both of the confining beds release water from storage into the aquifer being tested, the Theis method of solution is no longer valid. Hantush developed an equation for radial flow in an aquifer that is bounded by leaky aquifers that release water from storage. His main equations are:

$$T = \frac{Q}{4\pi s} H(u,\beta) \qquad \text{(G-10)}$$

where

$$H(u,\beta) = \int_u^\infty \frac{e^{-y}}{y} \operatorname{erfc} \frac{\beta/\sqrt{u}}{\sqrt{y(y-u)}}\, dy \qquad \text{(G-11)}$$

$$u = \frac{r^2 S}{4Tt}$$

as in the Theis equation, and

$$\beta = \frac{r}{4b}\left(\sqrt{\frac{K'S.'}{KS.}} + \sqrt{\frac{K'S.''}{KS.}}\right) \qquad \text{(G-12)}$$

where

K = hydraulic conductivity of main aquifer,
K',K" - hydraulic conductivities of semipervious confining layers,
S=bS. Storage coefficients of the main aquifer
S'=b'S.' and of the semipervious confining
S"=b"S." layers, respectively, and
S.,S.',S."=specific storage (storage coefficient per vertical unit of thickness) of the main aquifer and confining layers (b, b', and b"), respectively.

The versatility of Equations G-10 through G-12 lies in the fact that they are the general solutions for the drawdown distribution in all confined aquifers, whether they are leaky or nonleaky. Thus, if K' and K" approach zero or are made equal to zero, β approaches or equals zero, and Equation G-10 becomes Equation G-1, the Theis equation for nonleaky confined aquifers.

The aquifer transmissivity and storage coefficient are determined by first, fitting the logarithmic plot of drawdown vs. time to one of the type curves in Figure G-3. The values of H(u,β), u, t, and s at a match point are determined. Transmissivity is calculated using Equation G-10 and storage coefficient is calculated from Equation (G-2).

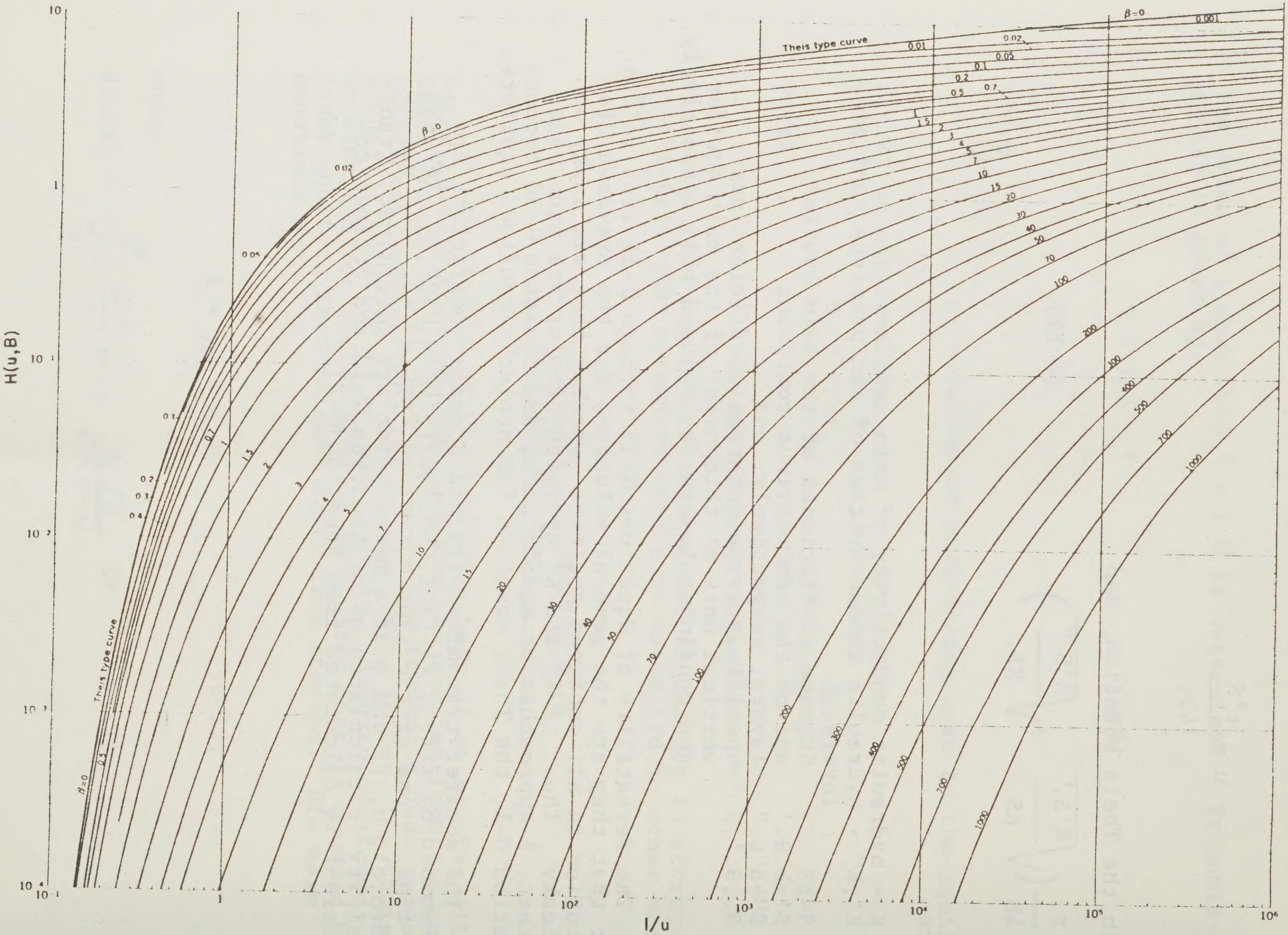


Figure G-3. Family of Type Curves for 1/u Versus $H(u,\beta)$, for Various Values of β

C. Nonsteady Radial Flow in an Unconfined Aquifer with Delayed Yield from Storage

Theoretically, the previous analysis techniques cannot be used in the analysis of aquifer pump tests on unconfined aquifers. This is because one of the basic assumptions of these analytical techniques (with the exception of the "slug" test analysis) is that the release of water from storage is immediate in response to a drop in the head of the aquifer. For unconfined aquifers, the water from storage is often not released immediately from the pore spaces. Some of the water usually drains shortly after pumping starts. However, it will take some time before all of the pore water drains from the dewatered portion of the aquifer.

The equation that describes the drawdown in a well from pumping an unconfined aquifer is (Boulton, 1963):

$$s = \frac{Q}{4\pi T} \int_0^\infty 2\, J_o \left(\frac{r}{B}\, x\right) \left(1 - \frac{1}{x^2+1} \exp\left(-\frac{\alpha t x^2}{x^2+1}\right) - \varepsilon\right) \frac{dx}{x} \tag{G-13}$$

where

$$\alpha = \left(\frac{r}{B}\right)^2 T \Big/ r^2 S_\ell \tag{G-14}$$

$$B = \sqrt{\frac{T}{\alpha S_\ell}} \tag{G-15}$$

$$\varepsilon = \left(\frac{x^2}{x^2+1}\right) \exp(-\alpha n t (x^2+1)) \tag{G-16}$$

J_o = Bessel function of the first kind of zero order,

$$n = \frac{S_e + S_\ell}{S_e} \tag{G-17}$$

x = variable of integration

S_e = early time apparent specific yield

S_ℓ = later time specific yield

and T, Q, s, t, and r are as defined previously.

Equation G-13 is solved by fitting a log-log plot of time and drawdown to the right-hand set of curves in Figure G-1 (Type B curves) and selecting a match point for s, t, $W(u_{e\ell}, r/B)$, and $/u_{\ell}$. Transmissivity is then calculated from

$$T = \frac{114.6Q}{s} W(u_{e\ell}, \frac{r}{B}) \qquad \text{(G-18)}$$

and specific yield from

$$S_{\ell} = \frac{0.3Tt}{r^2 u_{\ell}} \qquad \text{(G-19)}$$

The early drawdown data is then fit to the left-hand curves (Type A curves) using the same r/B curve to which the late drawdown data was matched. A new match point is selected for s, t, $W(u_{e\ell}, r/B)$ and $1/u_e$. Transmissivity is calculated from Equation G-19 and early apparent specific yield is calculated from Equation G-20, substituting u_e for u_{ℓ}. The transmissivity calculated from the early data should have the same value as the transmissivity calculated from the late data.

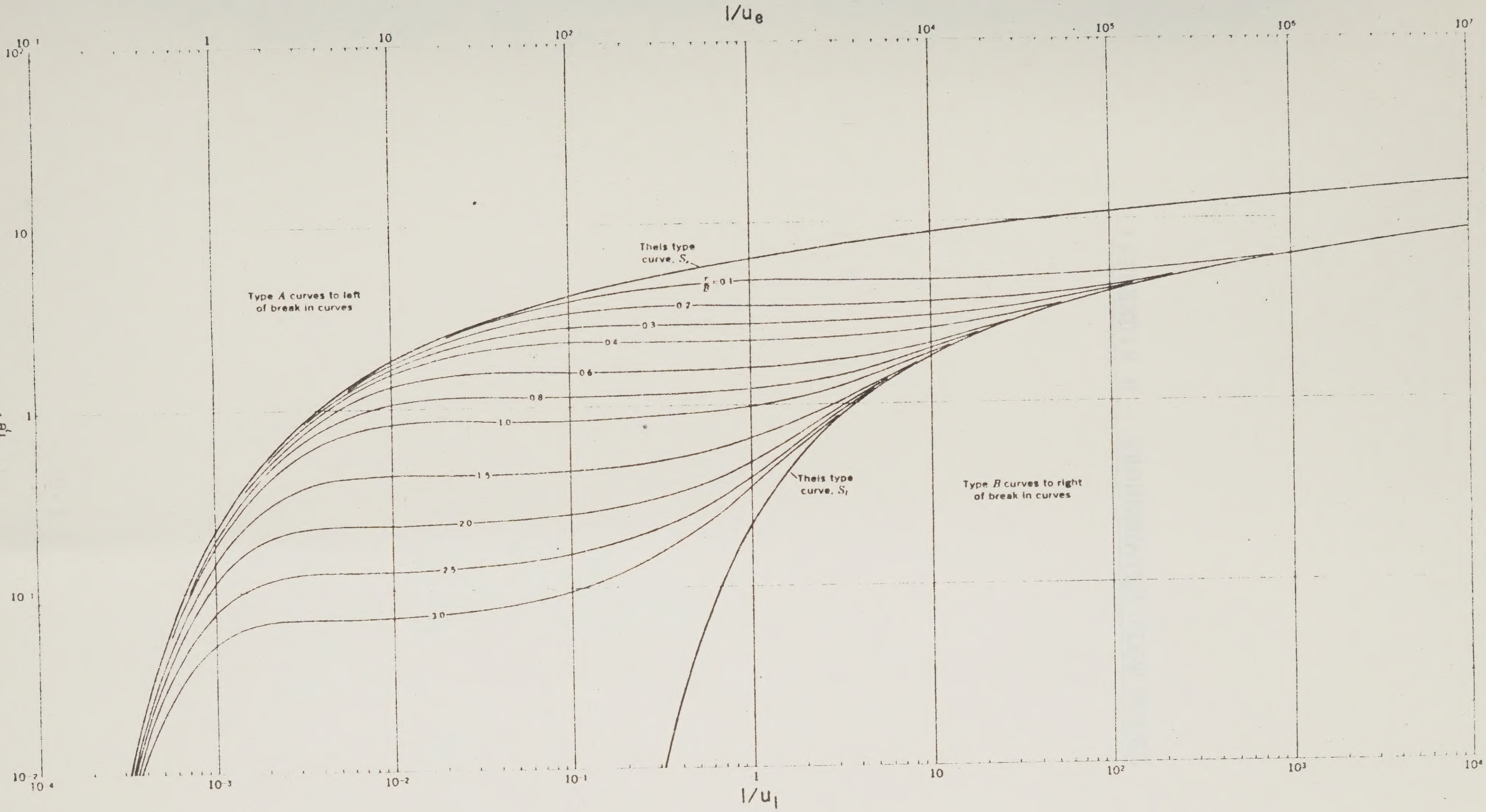


Figure G-IV. Family of Curves for Delayed Yield from Storage in an Unconfined Aquifer

APPENDIX H - GROUNDWATER FLOW MODEL

```
C
C    GROUNDWATER QUANITY MODEL
C     MODEL ADAPTED FOR THE POWDER RIVER BASIN
C
C
C     FLOW MODEL IS THE FOLLOWING:
C        COMPOSITE AQUIFER SIMULATION PROGRAM
C        LISTING FROM PAGES 51-52 OF 'SELECTED
C        DIGITAL COMPUTER TECHNIQUES FOR GROUNDWATER
C        EVALUATION', ILLINOIS STATE WATER SURVEY
C        BULLETIN 55, 1971, BY T.A. PRICKETT AND
C        C.G. LONNQUIST.  FLOW MODEL HANDLES
C        HETEROGENEOUS AQUIFERS WITH LEAKY AND/OR
C        NONLEAKY, INDUCED INFILTRATION, EVAPOTRANS-
C        PIRATION, ARTESIAN TO WATER-TABLE STORAGE
C        COEFFICIENT CONVERSION, ARTESIAN AND/OR
C        WATER TABLE CONDITIONS, AND VARIABLE NET
C        WITHDRAWAL RATES.  IN ADDITION, PRINTOUT
C        OF INPUT DATA, VARIABLE GRID INTERVALS,
C        AND VELOCITY CALCULATIONS ARE PROVIDED.
C
C    THIS MODEL CREATES A FILE FROM WHICH THE WATER
C     QUALITY MODEL (POLLUTE) IS RUN
C
C     DEFINITION OF VARIABLES
C
C     HO(I,J)-----HEADS AT START OF TIME
C                 INCREMENT (I,J)
C     H(I,J)------HEADS AT END OF TIME
C                 INCREMENT (FT)
C     SF1(I,J)----STORAGE FACTOR FOR
C                 ARTESIAN CONDITIONS (GAL)
C     SF2(I,J)----STORAGE FACTOR FOR WATER-
C                 TABLE CONDITIONS (GAL/FT)
C     Q(I,J)------CONSTANT WITHDRAWAL
C                 RATES (GPD)
C     PERM(I,J,1)-HYDRAULIC CONDUCTIVITY OF
C                 AQUIFER BETWEEN I,J AND I,J+1
C               (GAL/DAY/SQ FT)
C     PERM(I,J,2)-HYDRAULIC CONDUCTIVITY OF
C                 AQUIFER BETWEEN I,J, AND I+1,J
C                 (GAL/DAY/SQ FT)
C     T(I,J,1)----AQUIFER TRANSMISSIVITY
C                 BETWEEN I,J AND I,J+1
C                 (GAL/DAY*FT)
C     T(I,J,2)----AQUIFER TRANSMISSIVITY
C                 BETWEEN I,J AND I+1,J
C     BOT(I,J)----ELEVATION OF BOTTOM OF
C                 AQUIFER (FT)
C     R(I,J)------RECHARGE FACTOR
C                 (GAL/DAY/FT)
C     RH(I,J)-----ELEVATION OF LAND OR
C                 STREAM SURFACE (FT)
C     RD(I,J)-----ELEVATION OF BOTTOM OF
C                 STREAMBED OR ELEVATION
C                 BELOW WHICH EVAPOTRANS-
C                 PIRATION CEASES (FT)
```

```
C      CH(I,J)-----ELEVATION OF TOP OF
C                  AQUIFER (FT)
C                  (GAL/DAY*FT)
C      B-----------PEACEMAN-RACHFORD
C                  B ARRAY
C      G-----------PEACEMAN-RACHFORD
C                  G ARRAY
C      AA,BB,CC,DD-COEFFICIENTS IN WATER
C                  BALANCE EQUATIONS
C      NR----------NO. OF ROWS IN MODEL
C      NC----------NO. OF COLUMNS IN MODEL
C      NSTEPS------NO. OF TIME INCREMENTS
C      DELTA-------TIME INCREMENTS (DAYS)
C      HH,S1,QQ,TT-EXAMPLE MODEL
C                  DEFAULT VALUES
C      I-----------MODEL COLUMN NUMBER
C      J-----------MODEL ROW NUMBER
C      IP----------I COORDINATE OF PUMP
C      JP----------J COORDINATE OF PUMP
C      P(K,KC)-----PUMPING RATE AT WELL
C                  K AT RATE KC (GPD)
C      NP----------NUMBER OF PUMPS
C      NSP---------NUMBER OF TIME INCREMENTS
C                  PER PUMPAGE CHANGE
C      NRT---------NUMBER OF RATES IN
C                  PUMPING SCHEDULE
C       R2(I,J)------UNDERFLOW RECHARGE FACTOR(GPD/FT)
C       RH2(I,J)-----FIXED HEAD DISTRIBUTION UNDER MODEL LAYER
C       QET(I,J)-----EVAPOTRANSPIRATION DUE TO PHREATOPHYTES
C                      THIS IS THE VALUE AT H GE RH3,(GPD)
C       R3(I,J)------ET DEPTH FACTOR (GPD/FT)
C       RD3(I,J)-----ROOT DEPTH OF PHREATOPHYTES AS AN ELEVATION
C                      LOWER LIMIT OF TRANSPIRATION OF PHREATOPHYTES(FT)
C       RH3(I,J)-----ELEVATION OF MAXIMUM ET LEVEL,OFTEN THE LAND
C                      SURFACE,(FT)
C       F1------HEAD PREDICTION PARAMETER-DEFAULT=1.0
C              MAKE SMALL WHEN AT OR CLSE TO STEADY STATE(<.001)
C              MAKE=1.0 ON TRANSIENT CONDITIONS
C
C
C     INPUT=TAPE5-SETUP FOR PROGRAM INPUT DECK(SEE BULLETIN 55)
C     OUTPUT=TAPE6-LISTS NUMERICAL OUTPUT OF EACH STEP
C     TAPE7-PUNCHES A NEW INPUT DECK WITH THE INITIAL HEADS
C         REPLACED BY THE LAST COMPUTED HEADS
C     TAPE8-FILE USED TO RUN THE POLLUTE MODEL
C     TAPE9-FILE WITH THE CATEGORY PRINTOUT
C     TAPE4-INPUT FILE FOR EVAPOTRANSPIRATION DATA
C
      PROGRAM GWMOD6(INPUT,OUTPUT,TAPE4,TAPE7,TAPE8,TAPE9,TAPE5=INPUT,
     1TAPE6=OUTPUT)
      INTEGER OUT,OUT2,OUT1
      DIMENSION IP(100),JP(100),P(100,12),TAB(2,20),TITLE(40),ROW(50)
      COMMON/EXTRA/PERM(30,48,2),T(30,48,2),
     1SF1(30,48),SF2(30,48)
      COMMON/EXTRA3/ITER,NSTEPS,DL(30,48),ISTEP,KG
      COMMON/VEL/NC,NR
      1G(50),B(50),R(30,48),TIME,ERROR,E
       COMMON/AQUI/H(30,48),RH(30,48),
      1DELTA,Q(30,48),SOR(30,48)
       COMMON/VAR/DELX(50),DELY(50)
       COMMON/AQUI2/RD(30,48),BOT(30,48),R2(30,48),RH2(30,48)
C
C
C      DEFINE INPUT AND OUTPUT DEVICE NUMBERS
C
       IN=5
       OUT=6
       OUT1=9
C     READ TITLE AND CATEGORIES
C
       READ(IN,1005)TITLE
 1005  FORMAT(20A4/20A4)
       READ(IN,1006)NT,((TAB(I,J),I=1,2),J=1,NT)
 1006  FORMAT(I2,13(A1,F5.0)/7(A1,F5.0))
C
C  WRITE TITLE
       WRITE(OUT,1022)TITLE
       WRITE(OUT1,1022)TITLE
 1022  FORMAT(1H0,3X,20A4/4X,20A4)
C
C  READ THE WATER BALANCE CARD
C     IX1.LT. 0 THEN NO WATER BALANCE COMPUTED
C     IX1 .GT. 0 THEN COMPUTE WATER BALANCE FOR EACH TIME STEP
C            ON NODES IX1 THRU IX2 AND JX1 THRU JX2
C
       READ(5,1021)IX1,IX2,JX1,JX2
 1021  FORMAT(4I5)
C
C      READ PARAMETER CARD AND
C      DEFAULT VALUE CARD
C
       READ(IN,10)NSTEPS,DELTA,ERROR,F1,
      1NC,NR,TT,S1,HH,QQ,RR,RRH,RRD,S2,CCH,PP,BOTT,RR2,RRH2
10     FORMAT(I6,3F6.0/2I6,13F6.0)
C
C       WRITE OUT PARAMETER AND DEFAULT VALUES
C
       WRITE(OUT,8)
8      FORMAT(/* VALUES ON PARAMETER CARD*)
       WRITE(OUT,11)
11     FORMAT(/* NSTEPS  DELTA  ERROR*)
       WRITE(OUT,12)NSTEPS,DELTA,ERROR
12     FORMAT(I7,2E8.2)
       WRITE(OUT,7)
7      FORMAT(/* VALUES ON DEFAULT VALUE CARD*)
       WRITE(OUT,13)
13     FORMAT(/* NC NR          TT           S1           *
      1,*   S2          HH          QQ          RR      *
      2,* RRH      PP     BOTT       RRD      CCH*)
       WRITE(OUT,14)NC,NR,TT,S1,S2,HH,QQ,
      2RR,RRH,PP,BOTT,RRD,CCH
14     FORMAT(2I3,6E11.3,2F7.0,3F7.2)
C
```

```
C     READ PUMP PARAMETER CARD
C
      READ(IN,15) NP,NSP,NRT
15    FORMAT(3I6)
C
C     WRITE PUMP PARAMETER CARD
C
      WRITE(OUT,6)
6     FORMAT(/* PUMP PARAMETER VALUES*)
      WRITE(OUT,21)
21    FORMAT(/*    NP   NSP   NRT*)
      WRITE(OUT,22)NP,NSP,NRT
22    FORMAT(3I6)
C
C     READ PUMPING SCHEDULES
C
      DO 16 I=1,NP
16    READ(IN,17) IP(I),JP(I),
     1(P(I,K),K=1,NRT)
17    FORMAT(2I3,12F6.0)
C
C     WRITE PUMPING SCHEDULES
C
      WRITE(OUT,27)
27    FORMAT(/* PUMPING SCHEDULES*)
      WRITE(OUT,18)
18    FORMAT(* IP JP        P1        P2        P3*
     1,*        P4        P5        P6        P7*
     2,*        P8        P9         P10        P11*
     3,*       P12*)
      DO 9 I=1,NP
      WRITE(OUT,19)IP(I),JP(I),(P(I,M),M=1,NRT)
19    FORMAT(2I3,1P12E10.3/)
9     CONTINUE
C
C     READ VARIABLE GRID SIZES
C
      READ(IN,23)(DELX(I),I=1,NC)
23    FORMAT(10F8.0)
      READ(IN,23)(DELY(J),J=1,NR)
      WRITE(OUT,28)
28    FORMAT(/* VALUES OF ROW J AND DELY*)
      DO 25 J=1,NR
25    WRITE(OUT,26)J,DELY(J)
      WRITE(OUT,29)
29    FORMAT(/* VALUES OF COLUMN I AND DELX*)
      DO 24 I=1,NC
      WRITE(OUT,26)I,DELX(I)
26    FORMAT(14X,I5,F8.0)
24    CONTINUE
C
C     FILL ARRAYS WITH DEFAULT VALUES
C
      DO 20 I=1,NC
      DO 20 J=1,NR
      T(I,J,1)=TT
      T(I,J,2)=TT
      PERM(I,J,1)=PP
      PERM(I,J,2)=PP
      SF1(I,J)=S1
      SF2(I,J)=S2
      H(I,J)=HH
      HO(I,J)=HH
      R(I,J)=RR
      R2(I,J)=RR2
      RH2(I,J)=RRH2
      RH(I,J)=RRH
      RD(I,J)=RRD
      CH(I,J)=CCH
      BOT(I,J)=BOTT
20    Q(I,J)=QQ
C
C
C      READ AND WRITE NODE CARDS
C
      WRITE(OUT,35)
35    FORMAT(/* NODE CARD VALUES*)
      WRITE(OUT,41)
41    FORMAT(/*  I  J              T1           T2          SF1*
     1,*          SF2          H            Q           R*
     2,*       RH  PERM1  PERM2      BOT       RD          CH*)
30    READ(IN,40)I,J,T(I,J,1), T(I,J,2),
     1SF1(I,J),H(I,J),Q(I,J),R(I,J),RH(I,J),
     2RD(I,J),SF2(I,J),CH(I,J),PERM(I,J,1),
     3PERM(I,J,2),BOT(I,J),R2(I,J),RH2(I,J)
      IF(EOF(5))50,1001
40    FORMAT(2I3,2F6.0,2F4.0,11F6.0)
 1001 WRITE(OUT,42)I,J,T(I,J,1),T(I,J,2),SF1(I,J),
     1SF2(I,J),H(I,J),Q(I,J),R(I,J),RH(I,J),PERM(I,J,1),
     2PERM(I,J,2),BOT(I,J),RD(I,J),CH(I,J)
42    FORMAT(2I3,2F10.0,2F10.3,2F10.0,1F10.3,6F7.0)
      HO(I,J)=H(I,J)
      GO TO 30
50    CONTINUE
C
C   READ IN ET DATA
      CALL INPLNT
C
C      ADJUST AQUIFER PARAMETERS FOR VARIABLE GRID
C
      DO 45 I=1,NC
      DO 45 J=1,NR
      T(I,J,1)=T(I,J,1)*2*DELX(I)/(DELY(J)+DELY(J+1))
      T(I,J,2)=T(I,J,2)*2*DELY(J)/(DELX(I)+DELX(I+1))
      SF1(I,J)=SF1(I,J)*7.48*DELX(I)*DELY(J)
      SF2(I,J)=SF2(I,J)*7.48*DELY(J)*DELX(I)
      IF(SF1(I,J) .LE.0. .OR. SF2(I,J) .LE.0.)GO TO 705
      PERM(I,J,1)=2*PERM(I,J,1)*DELX(I)/(DELY(J)+
     1DELY(J+1))
45    PERM(I,J,2)=2*PERM(I,J,2)*DELY(J)/(DELX(I)+
     1DELX(I+1))
C
      OUT2=8
      WRITE(OUT2,1002)NC,NR,NSTEPS
 1002 FORMAT(3I5)
      DO 701 I=1,NC
      DO 701 J=1,NR
       WRITE(OUT2,1003)I,J,PERM(I,J,1),PERM(I,J,2),SF1(I,J),SF2(I,J)
     1 ,R(I,J),RD(I,J),RH(I,J),CH(I,J),BOT(I,J),DELX(I),
     2  DELY(J)
 1003 FORMAT(2I5,11E10.3)
  701 CONTINUE
C     START OF SIMULATION
C
      TIME=0
      DELI=DELTA
      KG=0
      KC=1
      DO 280 ISTEP=1,NSTEPS
C
C     ENTER PUMPAGE SCHEDULES
C
      Z=(ISTEP-1.0)/NSP+1.0
      IF(Z-KC)49,46,49
 46   DO 47 K=1,NP
      I=IP(K)
      J=JP(K)
 47   Q(I,J)=P(K,KC)
      DELTA=DELI
      KC=KC+1
 49   CONTINUE
C
C  COMPUTE TRANSPIRATION FROM PHREATOPHYTES
      CALL PLANT(F1)
C
      CALL HSOLVE(F1)
C
C
C  OUTPUT TO TAPE FILE FOR POLLUTE MODEL
C
      WRITE(OUT2,1004)ISTEP,TIME,DELTA,((H(I,J),I=1,NC),J=1,NR),
     1((Q(I,J),I=1,NC),J=1,NR)
 1004 FORMAT(I5,2G10.1,/(10E10.3))
C     PRINT RESULTS
C
      WRITE(OUT,301)TIME,ITER,E
      WRITE(OUT1,301)TIME,ITER,E
 301  FORMAT(////1X,*TIME ELAPSED SINCE PUMPING *
     1,*STARTED=*,G7.2,1X,*DAYS*/1X,*NUMBER OF *
     2,*ITERATIONS FOR THIS TIME INCREMENT=*
     3,I5/1X,*SUM OF CHANGES IN HEAD FOR ALL NODE*
     4,* POINTS=*,E20.7,*FT.*)
      WRITE(OUT,302)
 302  FORMAT(/58X,*WATER LEVEL ELEVATIONS*
     1,/58X,22(*!*))
      DELTA=DELTA*1.2
      DO 280 J=1,NR
      JJ=NR+1-J
      DO 312 I=1,NC
      DO 311 K=1,NT
      IF(+H(I,JJ)-TAB(2,K))312,312,311
```

```
             311 CONTINUE
             312 ROW(I)=TAB(1,K)
                 WRITE(OUT1,1008)(ROW(K),K=1,NC)
            1008 FORMAT(2X,50A2)
           280    WRITE(OUT,290)J,(H(I,J),I=1,NC)
           290    FORMAT(I5,5X,10F10.4/(12X10F10.4))
           C
           C  WRITE NEW DATA FILE
           C
                  CALL WDATA
           C
           C  COMPUTE THE WATER BALANCE
                  IF(IX1 .GT. 0)CALL BALANC(IX1,IX2,JX1,JX2)
           C
                  STOP
             705 WRITE(6,2001)I,J,SF1(I,J),SF2(I,J)
            2001 FORMAT(//5X,* BAD INPUT DATA *,2I5,2E10.2)
                  STOP 0001
                  END
```

```
CARD NR. SEVERITY  DETAILS     DIAGNOSIS OF PROBLEM

    300      I              CONTROL VARIABLE IN COMMON OR EQUIVALENCED, OPTIMIZATION MAY BE INHIBITED.
    329      I     22CD 330 FIELD WIDTH OF A CONVERSION DESCRIPTOR SHOULD BE AS LARGE AS THE MINIMUM SPECIFIED FOR THAT DESCRIPTOR.
```

```
C
C     *******************************************
C     THIS SUBROUTINE SOLVES FOR THE HEADS OF THE
C     AQUIFER SITUATION. THIS CODE COMES DIRECTLY
C     FROM BULLETIN 55.
C     *******************************************
C
      SUBROUTINE HSOLVE(F1)
      COMMON/EXTRA3/ITER,NSTEPS,DL(30,48),ISTEP,KG
      COMMON/EXTRA2/CH(30,48),HO(30,48),G(50),B(50),R(30,48),TIME,
     1ERROR,E
      COMMON/EXTRA/PERM(30,48,2),T(30,48,2),SF1(30,48),SF2(30,48)
      COMMON/AQUI/H(30,48),RH(30,48),DELTA,Q(30,48)
      COMMON/AQUI2/RD(30,48),BOT(30,48),R2(30,48),RH2(30,48)
      COMMON/VEL/NC,NR
      COMMON/EVAP/ET(12),DEN(30,48),ACRE(30,48),GR(12),R3(30,48),
     1RH3(30,48),RD3(30,48),QET(30,48)
C     PREDICT HEADS FOR NEXT
C     TIME INCREMENT
C
49    DO 51 I=1,NC
      DO 51 J=1,NR
      D=H(I,J)-HO(I,J)
      HO(I,J)=H(I,J)
      IF(F1 .LE. 0.)F1=1.0
      IF(DL(I,J).EQ.0.0)GO TO 48
      IF(ISTEP.GT.2)F=D/DL(I,J)
      IF(F.GT.5)F=5.0
      IF(F.LT.0.0)F=0.0
 48   DL(I,J)=D
      H(I,J)=H(I,J)+D*F*F1
      IF(H(I,J).LE.BOT(I,J))H(I,J)=BOT(I,J)+0.01
  51  CONTINUE
C
C     REFINE HEADS
C
C
C     UPDATE TIME AND INITIALIZE ERROR
C     AND ITERATION COUNTER
C
      TIME=TIME+DELTA
      KG=KG+1
      ITER=0
52    F=0.0
      ITER=ITER+1
C
C     COLUMN CALCULATIONS
C     ALLOW FOR PLUG-IN MODEL OF ANY SIZE FOR
C     DETAILED STUDY---EXAMPLE HERE IS 10X10 MODEL
C     PLUG-IN  AT TOTAL MODEL GRID NUMBERS 10-20
C     IN BOTH THE I AND J DIRECTIONS
C
C     ADDITIONAL PROVISIONS ARE MADE TO RECONNECT
C     PLUG-IN MODEL TO REGIONAL MODEL ONCE EVERY
C     10 ISTEPS.  DISCONNECTING PLUG-UN AND REGIONAL
C     MODELS WILL NOT EFFECT ACCURACY AS LONG AS
C     WATER-LEVEL CHANGES DUE TO STRIP MINING DO
```

```
C     NOT GO BEYOND PLUG-IN MODEL DURING 10 TIME
C     INCREMENTS
C
C     Z=(ISTEP-1.0)/10+1
C     IF(Z-KG)10,20,10
 20   III=1
      IIII=NC
      JJJ=1
      JJJJ=NR
      GO TO 11
C10   III=10
C     IIII=20
C     JJJ=10
C     JJJJ=20
 11   CONTINUE
      DO 160 II=III,IIII
      I=II
      IF(MOD(ISTEP+ITER,2).EQ.1)I=IIII-I+1
      DO 140 J=JJJ,JJJJ
C
C     CALCULATE PEACEMAN-RACHFORD
C     B AND G ARRAYS
C
      AA=0.0
C  EVAPOTRANSPIRATION
      QQET=RD3(I,J)*R3(I,J)
      RB1=1.
      IF(H(I,J) .LT. RD3(I,J))QQET=0.
      IF(H(I,J) .LT. RD3(I,J))RB1=0.
      IF(H(I,J) .GT. RH3(I,J))RB1=0.
      IF(H(I,J) .GT. RH3(I,J))QQET=-QET(I,J)
      IF(H(I,J).LT.BOT(I,J))H(I,J)=BOT(I,J)
      RE2=RH2(I,J)*R2(I,J)
      IF(H(I,J).LT.RD(I,J))GO TO 53
      RE=RH(I,J)*R(I,J)
      RB=1.0
      GO TO 54
 53   RE=(RH(I,J)-RD(I,J))*R(I,J)
      RB=0.0
 54   IF(H(I,J).LT.CH(I,J))GO TO 55
      S=SF1(I,J)
      GO TO 56
 55   S=SF2(I,J)
  56  BB=S/DELTA+R(I,J)*RB+R2(I,J)+(R3(I,J)*RB1)
      DD=HO(I,J)*S/DELTA-Q(I,J)+RE+RE2+QQET
      IF(BB .LE. 0.)WRITE(6,*)QQET,QET(I,J),BB,DD,I,J
      IF((HO(I,J)-CH(I,J))*(H(I,J)-CH(I,J)).LT.0.0)DD=DD+
     1(HO(I,J)-CH(I,J))*(SF1(I,J)-SF2(I,J))/DELTA
      CC=0.0
      IF(J-1)60,70,60
 60   AA=-T(I,J-1,1)
      BB=BB+T(I,J-1,1)
 70   IF(J-JJJJ)80,90,80
 80   IF(PERM(I,J,1).EQ.0.0)GO TO 85
      T(I,J,1)=PERM(I,J,1)*SQRT((AMIN1(H(I,J),CH(I,J))-
     1BOT(I,J))*(AMIN1(H(I,J+1),CH(I,J+1))-BOT(I,J+1)))
 85   CC=-T(I,J,1)
```

```
      BB=BB+T(I,J,1)
   90 IF(I-1)100,110,100
  100 BB=BB+T(I-1,J,2)
      DD=DD+H(I-1,J)*T(I-1,J,2)
  110 IF(I-IIII)120,130,120
  120 IF(PERM(I,J,2).EQ.0.0)GO TO 125
      T(I,J,2)=PERM(I,J,2)*SQRT((AMIN1(H(I,J),CH(I,J))-
     1BOT(I,J))*(AMIN1(H(I+1,J),CH(I+1,J))-BOT(I+1,J)))
  125 BB=BB+T(I,J,2)
      DD=DD+H(I+1,J)*T(I,J,2)
  130 W=BB-AA*B(J-1)
      B(J)=CC/W
  140 G(J)=(DD-AA*G(J-1))/W
C
C     RE-ESTIMATE HEADS
C
      E=E+ABS(H(I,JJJJ)-G(JJJJ))
      H(I,JJJJ)=G(JJJJ)
      N=JJJJ-1
  150 HA=G(N)-B(N)*H(I,N+1)
      E=E+ABS(HA-H(I,N))
      H(I,N)=HA
      N=N-1
      IF(N.GT.JJJ-1)GO TO 150
      DO 160 N=JJJ,JJJJ
      IF(H(I,N).GT.BOT(I,N))GO TO 160
      E=E+BOT(I,N)+0.01-H(I,N)
      H(I,N)=BOT(I,N)+0.01
  160 CONTINUE
C
C     ROW CALCULATIONS
C
C     Z=(ISTEP-1)/10+1
C     IF(Z-KG)30,40,30
   40 JJJ=1
      JJJJ=NR
      III=1
      IIII=NC
      GO TO 31
C30   JJJ=10
C     JJJJ=20
C     III=10
C     IIII=20
   31 CONTINUE
      DO 270 JJ=JJJ,JJJJ
      J=JJ
      IF(MOD(ISTEP+ITER,2).EQ.1)J=JJJJ-J+1
      DO 250 I=III,IIII
      AA=0.0
C  EVAPOTRANSPIRATION
      QQET=RD3(I,J)*R3(I,J)
      RB1=1.0
      IF(H(I,J) .LT. RD3(I,J))QQET=0.
      IF(H(I,J) .LT. RD3(I,J))RB1=0.
      IF(H(I,J) .GT. RH3(I,J))RB1=0.
      IF(H(I,J) .GT. RH3(I,J))QQET=-QET(I,J)
      RE2=RH2(I,J)*R2(I,J)
      IF(H(I,J).LT.RD(I,J))GO TO 163
      RE=RH(I,J)*R(I,J)
      RB=1.0
      GO TO 164
  163 RE=(RH(I,J)-RD(I,J))*R(I,J)
      RB=0.0
  164 IF(H(I,J).LT.CH(I,J))GO TO 165
      S=SF1(I,J)
      GO TO 166
  165 S=SF2(I,J)
  166 BB=S/DELTA+R(I,J)*RB+R2(I,J)+(R3(I,J)*RB1)
      DD=HO(I,J)*S/DELTA-Q(I,J)+RE+RE2+QQET
      IF((HO(I,J)-CH(I,J))*(H(I,J)-CH(I,J)).LT.0.0)DD=DD+
     1(HO(I,J)-CH(I,J))*(SF1(I,J)-SF2(I,J))/DFLTA
      CC=0.0
      IF(J-1)170,180,170
  170 BB=BB+T(I,J-1,1)
      DD=DD+H(I,J-1)*T(I,J-1,1)
  180 IF(J-JJJJ)190,200,190
  190 IF(PERM(I,J,1).EQ.0.0)GO TO 195
      T(I,J,1)=PERM(I,J,1)*SQRT((AMIN1(H(I,J),CH(I,J))-
     1BOT(I,J))*(AMIN1(H(I,J+1),CH(I,J+1))-BOT(I,J+1)))
  195 DD=DD+H(I,J+1)*T(I,J,1)
      BB=BB+T(I,J,1)
  200 IF(I-1)210,220,210
  210 BB=BB+T(I-1,J,2)
      AA=-T(I-1,J,2)
  220 IF(I-IIII)230,240,230
  230 IF(PERM(I,J,2).EQ.0.0)GO TO 235
      T(I,J,2)=PERM(I,J,2)*SQRT((AMIN1(H(I,J),CH(I,J))-
     1BOT(I,J))*(AMIN1(H(I+1,J),CH(I+1,J))-BOT(I+1,J)))
  235 BB=BB+T(I,J,2)
      CC=-T(I,J,2)
  240 W=BB-AA*B(I-1)
      B(I)=CC/W
  250 G(I)=(DD-AA*G(I-1))/W
C
C     RE-ESTIMATE HEADS
C
      E=E+ABS(H(IIII,J)-G(IIII))
      H(IIII,J)=G(IIII)
      N=IIII-1
  260 HA=G(N)-B(N)*H(N+1,J)
      E=E+ABS(H(N,J)-HA)
      H(N,J)=HA
      N=N-1
      IF(N.GT.III-1)GO TO 260
      DO 270 N=III,IIII
      IF(H(N,J).GT.BOT(N,J))GO TO 270
      E=E+BOT(N,J)+0.01-H(N,J)
      H(N,J)=BOT(N,J)+0.01
  270 CONTINUE
      IF(ITER.GT.150)GO TO 271
      IF(E.GT.ERROR) GO TO 52
  271 CONTINUE
      RETURN
      END
      SUBROUTINE WDATA
C
C THIS SUBROUTINE PRINTS OUT A NEW INPUT DATA DECK
C WITH THE FINAL HEAD(H) VALUES OF THE PROGRAM
C  AS THE INITIAL CONDITIONS FOR THE NEW RUN
C
      DIMENSION TITLE(20),P(12),DELX(48),X1(2),X2(7)
      COMMON/VEL/NC,NR
      COMMON/AQUI/H(30,48)
      REWIND 5
C  READ AND WRITE TITLE
 1001 FORMAT(20A4)
      READ(5,1001)TITLE
      WRITE(7,1001)TITLE
      READ(5,1001)TITLE
      WRITE(7,1001)TITLE
C  READ AND WRITE CATEGORIES
      READ(5,1009)NT,(TITLE(K),K=1,NT)
      WRITE(7,1009)NT,(TITLE(K),K=1,NT)
 1009 FORMAT(I2,13A6/7A6)
C  READ AND WRITE WATER BALANCE CONTROL CARD
      READ(5,1001)TITLE
      WRITE(7,1001)TITLE
C  READ AND WRITE PARAMETER AND DEFAULT VALUE CARDS
      READ(5,1001)TITLE
      WRITE(7,1001)TITLE
      READ(5,1008)TITLE,X1
 1008 FORMAT(20A4,2A5)
        WRITE(7,1008)TITLE,X1
C  READ AND WRITE PUMP CARDS
      READ(5,1002)NP,NSP,NRT
 1002 FORMAT(3I6)
      WRITE(7,1002)NP,NSP,NRT
      DO 5 I=1,NP
          READ(5,1003)IP,JP,(TITLE(K),K=1,NRT)
 1003     FORMAT(2I3,12A6)
          WRITE(7,1003)IP,JP,(TITLE(K),K=1,NRT)
    5 CONTINUE
C
C  READ AND WRITE VARIABLE GRID SIZES
      READ(5,1005)(DELX(I),I=1,NC)
 1005 FORMAT(10F8.0)
      WRITE(7,1005)(DELX(I),I=1,NC)
      READ(5,1005)(DELX(I),I=1,NR)
      WRITE(7,1005)(DELX(I),I=1,NR)
C
C   READ AND WRITE NODE CARDS
   10 READ(5,1006)I,J,X1,X2
      IF(EOF(5))25,20
 1006 FORMAT(2I3,2A8,4X,6A10,A6)
   20 IH=H(I,J)
      WRITE(7,1007)I,J,X1,IH,X2
 1007 FORMAT(2I3,2A8,I4,6A10,A6)
      GO TO 10
   25 RETURN
      END
      SUBROUTINE BALANC(IX1,IX2,JX1,JX2)
C
C   THIS SUBROUTINE COMPUTES THE WATER BALANCE FOR
C    EACH NODE BY CATEGORY AND SUMS UP THE TOTAL
C    WATER BALANCE FOR THE SET OF NODES DEFINED
C    BY IX1,IX2,JX1,JX2
C
      DIMENSION XX(4)
      COMMON/EXTRA/PERM(30,48,2),T(30,48,2),SF1(30,48),SF2(30,48)
      COMMON/EXTRA2/CH(30,48),HO(30,48),G(50),B(50),R(30,48)
      COMMON/AQUI/H(30,48),RH(30,48),DELTA,Q(30,48)
      COMMON/AQUI2/RD(30,48),BOT(30,48),R2(30,48),RH2(30,48)
      COMMON/VEL/NC,NR
      COMMON/EVAP/ET(12),DEN(30,48),ACRE(30,48),GR(12),R3(30,48),
     1RH3(30,48),RD3(30,48),GET(30,48)
C
      WRITE(6,1001)
 1001 FORMAT(///30X,* WATER BALANCE IN GPD   *//*  I    J   PUMPING
     1STREAMFLOW  NODE FLOW    STORAGE   UNDERFLOW      ET        WATER B
     2ALANCE*)
      SUMQ=0.
      DELTAQ=0.
      DO 5 I=IX1,IX2
        DO 10 J=JX1,JX2
C STREAMFLOW EXCHANGE
           X1=R(I,J)*(RH(I,J)-RD(I,J))
           IF(H(I,J) .LT. RD(I,J))GO TO 15
           X1=R(I,J)*(H(I,J)-RH(I,J))
   15      CONTINUE
C  INFLOW-OUTFLOW FORM SURROUNDING NODES
           XX(1)=0.
           XX(2)=0.
           XX(3)=0.
           XX(4)=0.
           IF(J .GE. NR)GO TO 1
           XX(1)=T(I,J,1)*(H(I,J)-H(I,J+1))
    1      IF(I .GE. NC)GO TO 2
           XX(2)=T(I,J,2)*(H(I,J)-H(I+1,J))
    2      IF(J .LE. 1)GO TO 3
           XX(3)=T(I,J-1,1)*(H(I,J)-H(I,J-1))
    3      IF(I .LE. 1) GO TO 4
           XX(4)=T(I-1,J,2)*(H(I,J)-H(I-1,J))
    4      CONTINUE
           X2=XX(1)+XX(2)+XX(3)+XX(4)
C  CHANGE IN STORAGE
           S=SF1(I,J)
           IF(H(I,J) .LT. CH(I,J))S=SF2(I,J)
           X3=(S*(H(I,J)-HO(I,J)))/DELTA
           IF(((H(I,J)-CH(I,J))*(HO(I,J)-CH(I,J))) .LT. 0.)X3=X3
     1      +((HO(I,J)-CH(I,J))*(SF1(I,J)-SF2(I,J)))/DELTA
C   UNDERFLOW
           X4=R2(I,J)*(H(I,J)-RH2(I,J))
C  TRANSPIRATION BY PHREATOPHYTES
      X5=R3(I,J)*(H(I,J)-RD3(I,J))
      IF(H(I,J) .LT. RD3(I,J))X5=0
      IF(H(I,J) .GT. RH3(I,J))X5=QET(I,J)
C  SUM FOR NODE
```

```
            DELTAQ=Q(I,J)+X1+X2+X3+X4+X5
C  WRITE RESULTS FOR THIS NODE
            WRITE(6,1002)I,J,Q(I,J),X1,X2,X3,X4,X5,DELTAQ
 1002       FORMAT(2I4,7G12.4)
C  SUM TOTAL EXCLUDING CONSTANT HEAD NODES
            IF(S .GT. 1E30)GO TO 10
            SUMQ=SUMQ+DELTAQ
   10    CONTINUE
    5 CONTINUE
C  WRITE TOTAL WATER BALANCE
      WRITE(6,1003)IX1,IX2,JX1,JX2,SUMQ
 1003 FORMAT(/5X,*WATER BALANCE FOR NODES *,I5,*  THRU *,I5,
     1*  AND  *,I5,* THRU  *,I5,* = *,G12.4,* GPD *)
      RETURN
      END
      SUBROUTINE INPLNT
C
C  THIS SUBROUTINE READS IN THE EVAPOTRANSPIRATION DATA TO BE USED
C  IN SUBROUTINE PLANT AND INITILIZES THESE VARIABLES
C
C     ET(K)-POTENTIAL EVAPOTRANSPIRATION,INCHES/DAY
C           IF F <1.0 (STEADY STATE),ET(1)=AVERAGE YEARLY ET
C           IF F=1.0  (TRANSIENT),ET(K),K=1,12=MONTHLY ET'S
C     DEN(I,J)-DIMENSIONLESS FACTOR TO ADJUST FOR VEGETATIVE DENSITY
C              OR OTHER FACTORS
C     ACRE(I,J)-ACREAGE OF PHREATOPHYTES,ACRES
C     GR(K)-GROWTH FACTOR TO ACCOUNT FOR MONTH TO MONTH CHANGES IN
C           VEGETATIVE DENSITY AND GROWTH,IF F<1.0,GR=1.0
C     RD3(I,J)-ROOT DEPTH OF PHREATOPHYTES AS AN ELEVATION,LOWER
C              LIMIT OF TRANSPIRATION BY PHREATOPHYTES,FT
C     RH3(I,J)-ELEVATION OF MAXIMUM ET LEVEL,OFTEN THE LAND SURFACE,FT
C
      COMMON/VEL/NC,NR
      COMMON/EVAP/ET(12),DEN(30,48),ACRE(30,48),GR(12),R3(30,48),
     1RH3(30,48),RD3(30,48)
C
C  INITIALIZE VARIABLES
      DO 5 I=1,NC
        DO 10 J=1,NR
          DEN(I,J)=0.
          ACRE(I,J)=0.
          RD3(I,J)=0.
          RH3(I,J)=1.0
   10   CONTINUE
    5 CONTINUE
C
C  READ POTENTIAL ET'S (IN/DAY) FOR EACH MONTH
      READ(4,1001)(ET(K),K=1,12)
      IF(EOF(4))15,20
 1001 FORMAT(12F6.0)
C  WRITE POTENTIAL ETS
C
   20 WRITE(6,1003)(ET(K),K=1,12)
 1003 FORMAT(/5X,*MONTHLY POTENTIAL ET*/5X,12G10.4)
C
C  READ AND WRITE GROWTH FACTORS FOR EACH MONTH
      READ(4,1001)(GR(K),K=1,12)
      WRITE(6,1004)(GR(K),K=1,12)
 1004 FORMAT(//5X,*MONTHLY GROWTH FACTORS*/5X,12G10.4)
C
      WRITE(6,1006)
 1006 FORMAT(//5X,*ET DATA*//2X,*  I     J  DENSITY   ACREAGE        RD3
     1RH3*//)
C
C  READ IN THE NODES AT WHICH TRANSPIRATION TAKES PLACE
   25 READ(4,1002)I,J,DEN(I,J),ACRE(I,J),RD3(I,J),RH3(I,J)
      IF(EOF(4))15,30
   30 WRITE(6,1005)I,J,DEN(I,J),ACRE(I,J),RD3(I,J),RH3(I,J)
 1005 FORMAT(2I5,G10.4,3F10.1)
 1002 FORMAT(2I3,4F8.0)
      IF(RD3(I,J) .GE. RH3(I,J))STOP 0005
   15 RETURN
```

```
          END
```

```
      SUBROUTINE PLANT(F)
C
C   THIS SUBROUTINE CALCULATES TRANSPIRATION BY PHREATOPHYTES
C      POTENTIAL ET CAN VARY BY MONTH AND GROWTH FACTORS ARE
C      AVAILABLE BY MONTH
C
C   IF A TRANSIENT RUN IS MADE (F=1.0), THEN THE SIMULATION MUST
C     USE 30 DAY TIME STEPS, AND ARRAYS ET AND GR MUST BE INPUT
C     SO THAT THE FIRST STEP IS THE CORRECT MONTH
C
C     ET(I,J)-POTENTIAL EVAPOTRANSPIRATION,INCHES/DAY
C             IF F<1.0 (STEADY STATE),ET(1)=AVERAGE YEARLY ET
C             IF F=1.0 (TRANSIENT),ET(K),K=1,12=MONTHLY ETIS
C     DEN(I,J)-DIMENSIONLESS FACTOR TO ADJUST FOR VEGETATIVE DENSITY
C              OR OTHER FACTORS
C     ACRE(I,J)-ACREAGE OF PHREATOPHYTE AT EACH NODE,ACRES
C     GR(K)-GROWTH FACTOR,TO ACCOUNT FOR MONTH TO MONTH CHANGES IN
C           VEGETATIVE DENSTIY AND GROWTH,IF F=1.0, GR=1.0
C     RD3(I,J)-ROOT DEPTH OF PHREATOPHYTES AS AN ELEVATION,LOWER
C              LIMIT OF TRANSPIRATION BY PHREATOPHYTES,FT
C     RH3(I,J)-ELEVATION OF MAXIMUM ET LEVEL,OFTEN THE LAND SURFACE,FT
C     QET(I,J)-ACTUAL MAXIMUM TRANSPIRATION,GPD
C     R3(I,J)-QET/(PH3-RD3)-FACTOR TO ACCOUNT FOR LESS ET AT GREATER
C                            DEPTHS,GPD/FT
C
      COMMON/EXTRA3/ITER,NSTEPS,DL(30,48),ISTEP
      COMMON/EVAP/ET(12),DEN(30,48),ACRE(30,48),GR(12),R3(30,48),
     1RH3(30,48),RD3(30,48),QET(30,48)
      COMMON/VEL/NC,NR
C
      KSTEP=MOD(ISTEP,12)
      IF(F .LT. 1.0)ET(KSTEP)=ET(1)
      IF(F .LT. 1.0)GR(KSTEP)=GR(1)
      DO 5 I=1,NC
        DO 10 J=1,NR
          QET(I,J)=ET(KSTEP)*DEN(I,J)*ACRE(I,J)*GR(KSTEP)*43560.
     1    *7.48/12.
          R3(I,J)=QET(I,J)/(RH3(I,J)-RD3(I,J))
   10  CONTINUE
    5 CONTINUE
      RETURN
      END
```

APPENDIX I - GROUNDWATER QUALITY MODEL

```
C     WATER QUALITY MODEL
C     CONVECTION-- PARTICLE IN A CELL MODEL
C     INCLUDES DISPERSION AND DECAY
C
C     THIS MODEL READS THE AQUIFER CHARACTERISTICS FROM A TAPE
C       GENERATED BY THE QUANTITY MODEL
C
C
C       DEFINITION OF VARIABLES
C
C       HO(I,J)-----HEADS AT START OF TIME
C                   INCREMENT (I,J)
C       H(I,J)------HEADS AT END OF TIME
C                   INCREMENT (FT)
C       SF1(I,J)----STORAGE FACTOR FOR
C                   ARTESIAN CONDITIONS (GAL)
C       SF2(I,J)----STORAGE FACTOR FOR WATER-
C                   TABLE CONDITIONS (GAL/FT)
C       Q(I,J)------CONSTANT WITHDRAWAL
C                   RATES (GPD)
C       PERM(I,J,1)-HYDRAULIC CONDUCTIVITY OF
C                   AQUIFER BETWEEN I,J AND I,J+1
C                 (GAL/DAY/SQ FT)
C       PERM(I,J,2)-HYDRAULIC CONDUCTIVITY OF
C                   AQUIFER BETWEEN I,J, AND I+1,J
C                   (GAL/DAY/SQ FT)
C       T(I,J,1)----AQUIFER TRANSMISSIVITY
C                   BETWEEN I,J AND I,J+1
C                   (GAL/DAY*FT)
C       T(I,J,2)----AQUIFER TRANSMISSIVITY
C                   BETWEEN I,J AND I+1,J
C       BOT(I,J)----ELEVATION OF BOTTOM OF
C                   AQUIFER (FT)
C       R(I,J)------RECHARGE FACTOR
C                   (GAL/DAY/FT)
C       RH(I,J)-----ELEVATION OF LAND OR
C                   STREAM SURFACE (FT)
C       RD(I,J)-----ELEVATION OF BOTTOM OF
C                   STREAMBED OR ELEVATION
C                   BELOW WHICH EVAPOTRANS-
C                   PIRATION CEASES (FT)
C       CH(I,J)-----ELEVATION OF TOP OF
C                   AQUIFER (FT)
C                   (GAL/DAY*FT)
C       B-----------PEACEMAN-RACHFORD
C                   B ARRAY
C       G-----------PEACEMAN-RACHFORD
C                   G ARRAY
C       AA,BB,CC,DD-COEFFICIENTS IN WATER
C                   BALANCE EQUATIONS
C       NR----------NO. OF ROWS IN MODEL
C       NC----------NO. OF COLUMNS IN MODEL
C       NSTEPS------NO. OF TIME INCREMENTS
C       DELTA-------TIME INCREMENTS (DAYS)
C       HH,S1,QQ,TT-EXAMPLE MODEL
C                   DEFAULT VALUES
C       I-----------MODEL COLUMN NUMBER
```

```
C      J-----------MODEL ROW NUMBER
C      IP----------I COORDINATE OF PUMP
C      JP----------J COORDINATE OF PUMP
C      P(K,KC)-----PUMPING RATE AT WELL
C                  K AT RATE KC (GPD)
C      NP----------NUMBER OF PUMPS
C      NSP---------NUMBER OF TIME INCREMENTS
C                  PER PUMPAGE CHANGE
C      NRT---------NUMBER OF RATES IN
C                  PUMPING SCHEDULE
C      NPART(I,J)--NUMBER OF PARTICLES WITHIN
C                  0.5 GRID INTERVAL OF NODE.
C      V(I,J,K)----MICROSCOPIC VELOCITY OF
C                  GROUNDWATER AT NODE I,J AND
C                  DIRECTION K.
C      TABLE(I)----WHERE NUMBER OF PARTICLES
C                  DRAINED BY SINKS ARE STORED
C                  FOR SINK MARKED LOCATIONS
C                  DURING TIME STEP ADVAN(DELP)
C      MOVE--------FUNCTION DEPENDENT ON PARTICLE
C                  COORDINATES X,Y, AND DELP.
C                  THE FUNCTION VALUE RETURNED IS
C                  EITHER ZERO OR A SINK NUMBER
C                  DECAY TAKES PLACE HERE ALSO
C      PL----------TOTAL AMOUNT OF POLLUTANT
C      NP----------TOTAL NUMBER OF PARTICLES
C                  IN SYSTEM
C      MAXP--------MAXIMUM NUMBER OF PARTICLES
C                  ALLOWED IN SYSTEM
C      PM----------PARTICLE MASS
C      DELTA-------TIME INCREMENT FOR FLOW
C                  MODEL, IN DAYS
C      DELP--------TIME INCREMENT PARTICLES
C                  ARE ALLOWED TO MOVE, IN DAYS---
C                  USUALLY THE SAME AS DELTA
C      DISP--------AQUIFER DISPERSIVITY IN FT
C      TRATIO------RATIO OF TRANSVERSE TO LONGITUDINAL DISPERSIVITY
C      TMAP--------TIME SINCE PARTICLES WERE
C                  FIRST ALLOWED TO MOVE, IN DAYS
C      MARK(I,J)---COORDINATES OF SINKS ARE I AND J.
C                  VALUE STORED IN MARK IS THE
C                  SINK NUMBER. IF MARK IS ZERO
C                  THEN THERE IS NO SINK.
C      X,Y---------MODEL COORDINATES OF WHERE
C                  PARTICLES WILL BE PLACED
C      DX,DY-------SPACIAL INCREMENT ADDED TO
C                  X,Y, COORDINATES OVER WHICH
C                  PARTICLES WILL BE PLACED OR MOVED
C     LIJ(I,J,K)--ONE LINE SUBROUTINE LIMITING
C                  VELOCITY CALCULATIONS TO
C                  INTERIOR OF MODEL.
C      VX,VY-------VELOCITY COMPONENTS OF PARTICLE
C      RANF-------CDC 6600 FTN RANDOM NUMBER GENERATOR
C                  PRODUCES NUMBERS BETWEEN 0 AND 1
C      EPOR--------EFFECTIVE POROSITY
C      APOR--------ACTUAL POROSITY
```

```
C     XL1---------TWICE THE MAXIMUM DISTANCE AWAY FROM THE CENTER OF
C                 THE NODE THAT PARTICLES WILL BE INITIATED BY SUBROUTINE
C                 SOURCE IN THE I DIRECTION-- EX  XL1=1 MEANS PARTICLES
C                 ARE RANDOMLY GENERATED .5 PLUS OR MINUS FROM THE
C                 SOURCE NODE CENTER
C     YL1---------TWICE THE MAXIMUM DISTANCE AWAY FROM THE CENTER OF THE
C                 NODE THAT PARTICLES WILL BE INITIATED BY SUBROUTINE
CC                SOURCE IN THE J DIRECTION
C     TL1---------FRACTION OF A TIME STEP A PARTICLE IS ALLOWED TO
C                 MOVE DURING THE GENERATION STEP
C                 STEPS TO BE TAKEN IN SUBROUTINE SOURCE, IF =0,THEN
C                 PARTICLES GENERATED RANDOMLY IN TIME THRU THE STEP
C                 IF =-10,THEN NO SUSTITUTIONS ARE MADE TO THE CONC
C                 ARRAY IN SUBROUTINE CONMAP
C      XL2--------TWICE THE MAXIMUM DISTANCE AWAY FROM THE CENTER OF THE
C                 NODE THAT PARTICLES CAN BE CAPTURED BY A SINK IN THE
C                 I DIRECTION
C      YL2--------TWICE THE MAXIMUN DISTANCE AWAY FROM THE CENTER OF THE
C                 NODE THAT PARTICLES CAN BE CAPTURED BY A SINK IN THE
C                 J DIRECTION
C      XLAMDA--------DECAY COEFFICIENT IN RECIPROCAL DAYS
C
C      XNPT(I,J)----NUMBER OF DECAYED PARTICLES AT EACH GRID NODE
C                   SAME AS NPART EXCEPT INCLUDES THE EFFECTS OF DECAY
C      PARTM(K)-----MASS OF EACH DECAYED PARTICLE
C
C
      PROGRAM POLLUT3(INPUT,OUTPUT,TAPE8,TAPE7,TAPE5=INPUT,TAPE6=
     1OUTPUT)
      INTEGER OUT
      DIMENSION TITLE(16)
      COMMON/EXTRA/PERM(30,48,2),T(30,48,2),
     1SF1(30,48),SF2(30,48)
      COMMON/EXTRA3/ITER,NSTEPS,DL(30,48),ISTEP,KG
      COMMON/POR/APOR,EPOR,CONSOR(30,48)
      COMMON/VEL/NC,NR,ANC,ANR,V(30,48,2)
      COMMON/TRACE/NP,MAXP,PM,DISP,TRATIO,
     1X(5001),Y(5001),MARK(30,48),TMAP
      COMMON/EXTRA2/CH(30,48),HO(30,48),
     1G(30),B(30),R(30,48),TIME,ERROR,E
      COMMON/AQUI/H(30,48),RH(30,48),
     1DELTA,Q(30,48),SOR(30,48)
      COMMON/VAR/DELX(50),DELY(50)
      COMMON/AQUI2/RD(30,48),BOT(30,48)
      COMMON/POL/X1,DX,Y1,DY,DELP
      COMMON/CONTRL/XL1,YL1,TL1,XL2,YL2
      COMMON/DECAY/XNPT(30,48),XLAMDA,PARTM(5001)
C
C
C      DEFINE INPUT AND OUTPUT DEVICE NUMBERS
C
      IN=5
      OUT=6
      IN2=8
C
C     TAPE5 FOR POLLUTANT PARAMETER INPUT
C     TAPE6 FOR OUTPUT
```

```
C     TAPE8 FOR INPUT FROM FLOW MODEL
C     TAPE7 FOR OUTPUT OF CONCENTRATION ARRAY
C           THAT IS INPUT TO SMOOTHING ROUTINE
C
C   READ AND WRITE TITLE
C
      READ(IN,1004)TITLE
 1004 FORMAT(8A10/8A10)
      WRITE(OUT,1005)TITLE
 1005 FORMAT(1H1,4X,8A10/5X,8A10)
C
C    READ GROUNDWATER FLOW MODEL PARAMETERS
C
      READ(IN2,1001)NC,NR,NSTEPS
 1001 FORMAT(3I5)
      DO 5 II=1,NC
      DO 5 JJ=1,NR
         READ(IN2,1002)I,J,PERM(I,J,1),PERM(I,J,2),SF1(I,J),SF2(I,J),
     1    R(I,J),RD(I,J),RH(I,J),CH(I,J),BOT(I,J),DELX(I),
     2    DELY(J)
 1002 FORMAT(2I5,11E10.3)
    5 CONTINUE
C
C
C     READ AND WRITE POLLUTION INITIAL CONDITIONS
C
      READ(IN,3)X1,DX,Y1,DY,DELP,ITIME
3     FORMAT(5F10.0,I10)
      WRITE(OUT,31)
31    FORMAT(/* INITIAL LOCATION OF PARTICLES*)
      WRITE(OUT,32)
32    FORMAT(* AND TIME INCREMENT DELP*)
      WRITE(OUT,4)
4     FORMAT(*           X1          DX          Y1*
     1,*      DY        DELP      ITIME        *)
      WRITE(OUT,3)X1,DX,Y1,DY,DELP,ITIME
C
C  READ AND WRITE THE CONTROL PARAMETERS FOR  THE SOURCE SUBROUTINE
C   AND THE SINKS(MOVE SUBROUTINE)
C   AND XLAMDA (DECAY COEFFICIENT IN RECIPROCAL DAYS)
C
      READ(IN,1006)XL1,YL1,TL1,XL2,YL2,XLAMDA
 1006 FORMAT(6F10.0)
      IF(XL2 .LE. 0.)XL2=1.0
      IF(YL2 .LE. 0.)YL2=1.0
      WRITE(OUT,1007)XL1,YL1,TL1,XL2,YL2,XLAMDA
 1007 FORMAT(/,*  CONTROL PARAMETERS FOR SOURCES AND SINKS  */,
     1*         XL1       YL1       TL1       XL2       YL2 */,1X,
     25F10.2//5X,* XLAMDA=*,G10.3/)
C
C     READ AND WRITE POLLUTION PARAMETERS
C
      READ(IN,1)PL,MAXP,PM,DISP,TRATIO,EPOR,APOR
1     FORMAT(1F10.3,I10,5F10.3)
      WRITE(OUT,33)
33    FORMAT(/* VALUES OF POLLUTION PARAMETERS*)
```

```
      2     FORMAT(/*          PL        MAXP          PM*
           1,*      DISP    TRATIO        EPOR        APOR*)
            WRITE(OUT,51)PL,MAXP,PM,DISP,TRATIO,EPOR,APOR
      51    FORMAT(1F10.0,I10,3G10.3,2E10.3)
            CALL INIT
      C
      C     READ AND WRITE SINK LOCATION AND
      C     IDENTIFYING NUMBER.
      C
            WRITE(OUT,34)
      34    FORMAT(/* LOCATION OF SINKS AND IDENTIFIER*)
            WRITE(OUT,52)
      52    FORMAT(/*  I  J MARK*)
      500   READ(IN,511)I,J,MRK
      511    FORMAT(3I3)
            IF(I.EQ.0.AND.J.EQ.0)GO TO 53
            MARK(I,J)=MRK
            WRITE(OUT,511)I,J,MARK(I,J)
            GO TO 500
      53    CONTINUE
      C
      C     READ AND WRITE SOURCE CONCENTRATION DATA
      C
            WRITE(OUT,61)
      61    FORMAT(/* LOCATION OF SOURCES AND THEIR*
           1,* CONCENTRATION*)
      63    READ(IN,60)I,J,CONSOR(I,J)
      60    FORMAT(2I3,1F14.4)
            IF(I.EQ.0.AND.J.EQ.0)GO TO 62
            WRITE(OUT,60)I,J,CONSOR(I,J)
            GO TO 63
      62    CONTINUE
      C
      C   READ GROUNDWATER HEADS AND PUMPAGES FROM TAPE8 FOR EACH TIME
      C      STEP-TAPE8 IS THE OUTPUT TAPE FROM GWMOD3
      C
       20    READ(IN2,1003)ISTEP,TIME,DELTA,((H(I,J),I=1,NC),J=1,NR),
           1((Q(I,J),I=1,NC),J=1,NR)
       1003 FORMAT(I5,2F10.1/(10F10.3))
            IF(EOF(IN2))15,10
         10 IF(ISTEP .LT. ITIME)GO TO 20
            CALL CLEAR
            DO 300 I=1,NC
            DO 300 J=1,NR
            IF(J .NE. NR)V(I,J,1)=-PERM(I,J,1)*(H(I,J+1)-H(I,J))/
           1(DELX(I)*EPOR*7.48052)
            IF(I .NE. NC)V(I,J,2)=-PERM(I,J,2)*(H(I+1,J)-H(I,J))/
           1(DELY(J)*EPOR*7.48052)
        300 CONTINUE
      C
            CALL GENP(PL)
            DO 303 I=1,15
      C
               CALL MAP
               CALL SUMMRY
               CALL SNKCON
               CALL CLEAR
```

```
                CALL ADVAN(DELP)
                CALL SOURCE
          C
           303  CONTINUE
290             CALL CONMAP
             IF(ISTEP .LT. NSTEPS) GO TO 20
          15 STOP
             END
```

```
C
C     ***********************************************
C     THIS FUNCTION PROVIDES PROPER
C     VELOCITIES TO SUBROUTINE VELO.
C     VELOCITIES WERE CALCULATED IN MAIN.
C     ***********************************************
C
      FUNCTION V(I,J,K)
      COMMON /VEL/NC,NR,ANC,ANR,VV(30,48,2)
      V=VV(I,J,K)
      RETURN
      END
```

```
C
C     ***********************************************
C     THIS SUBROUTINE CLEARS OUT NPART
C     AND TABLE
C     ***********************************************
C
      SUBROUTINE CLEAR
      COMMON /VEL/ NC,NR
      COMMON /FORMS/ TABLE(500),NPART(30,48)
      COMMON/DECAY/XNPT(30,48)
      DO 1 I=1,NC
      DO 1 J=1,NR
      XNPT(I,J)=0.
    1 NPART(I,J)=0
      DO 2 I=1,500
    2 TABLE(I)=0.0
      RETURN
      END
      C
      C      ********************************************
      C      THIS SUBROUTINE ADVANCES ALL PARTICLES
      C      TO THEIR NEW POSITIONS DURING TIME
      C      INCREMENT DELP
      C      ********************************************
      C
             SUBROUTINE ADVAN(DELP)
             COMMON/TRACE/NP,MAXP,PM,DISP,TRATIO,X(5001),
            1Y(5001),MARK(30,48),TMAP
             COMMON/DECAY/XNPT(30,48),XLAMDA,PARTM(5001)
             TMAP=TMAP+DELP
             K=0
      1      K=K+1
      2      IF(K.GT.NP) RETURN
      C
      C      IF A PARTICLE GOES INTO A SINK, THE LAST
      C      PARTICLE (NP) COORDINATES ARE THEN STORED
      C      IN THE THUS VACATED X(K) AND Y(K) POSITION.
      C
             IF(MOVE(X(K),Y(K),DELP,K).EQ.0) GO TO 1
             X(K)=X(NP)
             Y(K)=Y(NP)
             PARTM(K)=PARTM(NP)
             NP=NP-1
             GO TO 2
             END
```

```
C
C     *******************************************
C     THIS SUBROUTINE IS WHERE THE MARK ARRAY,
C     TMAP AND NP ARE ZEROED OUT AND WHERE ANC
C     AND ANR ARE INITIALYZED.
C     *******************************************
C
      SUBROUTINE INIT
      COMMON/TRACE/NP,MAXP,PM,DISP,TRATIO,X(5001),
     1Y(5001),MARK(30,48),TMAP
      COMMON/AQUI/H(30,48),RH(30,48),DELTA,Q(30,48)
     1,SOR(30,48)
      COMMON/EXTRA2/CH(30,48),HO(30,48),G(30),
     1B(30),R(30,48),TIME,F
      COMMON /VEL/ NC,NR,ANC,ANR
      COMMON/POR/APOR,EPOR,CONSOR(30,48)
      COMMON/DECAY/XNPT(30,48),XLAMDA,PARTM(5001)
      TMAP=0.
      NP=0
      ANC=NC
      ANR=NR
      DO 1 I=1,NC
      DO 1 J=1,NR
      SOR(I,J)=0.0
      CONSOR(I,J)=0.0
    1 MARK(I,J)=0
      DO 2 K=1,MAXP
      PARTM(K)=1.0
    2 CONTINUE
      RETURN
      END
```

```
C
C     ********************************************
C     THIS SUBROUTINE ENABLES PARTICLES
C     TO BE INITIATED IN X, Y SPACE AND OVER
C     TIME DELP RANDOMLY
C     ********************************************
C
      SUBROUTINE GENP(PL)
      COMMON/TRACE/NP,MAXP,PM,DISP,TRATIO,X(5001),Y(5001),MARK(30,48),
     1TMAP
      COMMON/POL/X1,DX,Y1,DY,DELP
      TMAP=TMAP+DELP
      P=PL
1     IF(RANF(0).GT.P/PM)RETURN
      P=P-PM
      XX=X1+DX*RANF(0)
      YY=Y1+DY*RANF(0)
      DE=DELP*RANF(0)
      IF(MOVE(XX,YY,DE,NP+1).EQ.0) CALL ADD(XX,YY)
      GO TO 1
      END
```

```
C
C     ********************************************
C     THIS SUBROUTINE ALLOWS PARTICLES TO BE
C     GENERATED FROM SPECIFIED SOURCES OF
C     POLLUTION AT A RATE GOVERNED BY FLOW FROM
C     THE SOURCE INTO THE AQUIFER.
C     POSSIBLE SOURCES WOULD BE LEACHATE FROM
C     SPOIL PILES, INFILTRATION FROM POLLUTED RIVERS,
C     INJECTION WELLS, LEACHATE FROM RECLAIMED LAND
C     AND ACCIDENTAL SPILLS.
C     ********************************************
C
      SUBROUTINE SOURCE
C
      COMMON/EXTRA2/CH(30,48),HO(30,48),
     1G(30),B(30),R(30,48)
      COMMON/AQUI/H(30,48),RH(30,48),
     1DELTA,Q(30,48),SOR(30,48)
      COMMON/VEL/NC,NR
      COMMON/POR/APOR,EPOR,CONSOR(30,48)
      COMMON/POL/X1,DX,Y1,DY,DELP
      COMMON/TRACE/NP,MAXP,PM
      COMMON/CONTRL/XL1,YL1,TL1
C
      DO 2 I=1,NC
      DO 2 J=1,NR
      A=0.
      DELSOR=DELP
      RATE=(RH(I,J)-H(I,J))*R(I,J)
      IF(Q(I,J).LT.0.0)RATE=-Q(I,J)
      IF(RATE.LE.0.0)GO TO 2
      IF(CONSOR(I,J).EQ.0.0)GO TO 2
      DELR=SOR(I,J)/RATE
      IF(DELR.GT.DELP)GO TO 4
    1 DELSOR=DELSOR-DELR
      XX=I*1.
      YY=J*1.
      XX=XX+XL1*RANF(0)-(XL1/2.)
      YY=YY+YL1*RANF(0)-(YL1/2.)
      DE=DELSOR*TL1
      IF(TL1 .LE. 0.)DE=DELSOR*RANF(0)
      IF(MOVE(XX,YY,DE,NP+1).EQ.0.0)CALL ADD(XX,YY)
      A=A+1
      IF(A.GT.1)GO TO 5
      P=RATE*(DELP-DELR)*CONSOR(I,J)*8.3453/1E6
    5 K=P/PM
      IF(K.LT.1)GO TO 3
      P=P-PM
      DELR=PM*1E6/(CONSOR(I,J)*8.3453*RATE)
      GO TO 1
    3 SOR(I,J)=(PM-P)*1E6/(CONSOR(I,J)*8.3453)
      GO TO 2
    4 SOR(I,J)=SOR(I,J)-DELP*RATE
    2 CONTINUE
      RETURN
```

```
C
C     *********************************************
C     THIS SUBROUTINE IS CALLED WHEN PARTICLES
C     ARE TO BE ADDED TO THE SYSTEM. IF
C     NUMBER OF PARTICLES TO BE ADDED IS
C     GREATER THAN MAXP THEN PM CHANGES WHILE
C     NP STAYS THE SAME.
C     *********************************************
C
      SUBROUTINE ADD(XX,YY)
      COMMON/TRACE/NP,MAXP,PM,DISP,TRATIO,X(5001),
     1Y(5001)
      NP=NP+1
      X(NP)=XX
      Y(NP)=YY
C     PRINT 1,NP,XX,YY
1     FORMAT(I5,2F10.2)
      IF(NP.LT.MAXP)RETURN
      K=RANF(0)*MAXP+1.0
      X(K)=X(NP)
      Y(K)=Y(NP)
      PM=PM*MAXP/(MAXP-1)
      NP=NP-1
      RETURN
      END
```

```
C
C     ********************************************
C     THIS FUNCTION MOVES THE PARTICLES TO NEW
C     LOCATIONS AS CALLED ON BY SUBROUTINES
C     ADVAN OR GENP.  IT ALSO KEEPS TABS ON THE
C     SINKS AND TABULATES WHEN PARTICLES
C     ENTER SAME.  ALSO LIMITS MOVEMENT OF
C     PARTICLES TO 0.2 GRIDS BEFORE USING NEW
C     VELOCITIES TO CONTINUE MOVEMENT
C     ALONG FLOW PATH.  FINALLY, THIS SUB-
C     ROUTINE COLLECTS INFORMATION ON
C     NUMBER OF PARTICLES IN VOLUMES OF
C     AQUIFER.
C     ********************************************
C
      FUNCTION MOVE(XX,YY,DEL,IPM)
      COMMON/VAR/DELX(50),DELY(50)
      COMMON/TRACE/NP,MAXP,PM,DISP,TRATIO,X(5001),
     1Y(5001),MARK(30,48)
      COMMON /FORMS/ TABLE(500),NPT(30,48)
      COMMON /VEL/ NC,NR,ANC,ANR
      COMMON/CONTRL/XL1,YL1,TL1,XL2,YL2
      COMMON/DECAY/XNPT(30,48),XLAMDA,PARTM(5001)
      D=DEL
      DMIX=1./(2.*DISP)
      DRATIO=SQRT(TRATIO)
C
C     THE FOLLOWING SECTION (TO THE NEXT COMMENT
C     CARD MARKED 'DO LOOP') IS A PSEUDO DO LOOP
C     BASED ON THE VALUE OF TIME, D, REMAINING FOR
C     MOVING A PARTICLE DURING A TIME INCREMENT
C     DELP.
C
1     IF(D.LE.0.0) GO TO 2
      CALL VELO(XX,YY,VX,VY)
C     LIMIT DISTANCE PARTICLE CAN MOVE BEFORE
C     USING NEW VALUES OF VELOCITY
      T=AMIN1(D,.2*ABS(DELX(XX)/VX),
     1.2*ABS(DELY(YY)/VY))
      D=D-T
      DX=VX*T
      DY=VY*T
      DD=SQRT(DX**2+DY**2)
      IF(DD .EQ. 0.0)DD=1.E-30
      RL=1.0/SQRT(DD*DMIX)
      RT=DRATIO*RL*ANORM(0)
      RL=RL*ANORM(0)
      IXX=XX+.5
      IYY=YY+.5
      XX=XX+(DX+RL*DX+RT*DY)/(DELX(IXX))
      YY=YY+(DY+RL*DY-RT*DX)/(DELY(IYY))
C
C     THESE NEXT TWO STATEMENTS LIMIT THE
C     MOVEMENT OF THE PARTICLES TO THE
C     PLAYING FIELD DEFINED BY GRID COORDINANTS
C     1,1; 1,NR; NC,1; AND NC,NR
```

```
      XX=AMIN1(ANC,AMAX1(XX,1.0))
      YY=AMIN1(ANR,AMAX1(YY,1.0))
C
C     CHECK TO SEE IF PARTICLE GOES INTO A SINK.
C     IF SO, SUM PARTICLE MASS INTO TABLE.
C
      IX=XX+0.5
      IY=YY+0.5
      MOVE=MARK(IX,IY)
      IF(ABS(XX-IX) .GT. (XL2/2.))MOVE=0
      IF(ABS(YY-IY) .GT. (YL2/2.))MOVE=0
      IF(MOVE.EQ.0)GO TO 1
C     'DO LOOP'--SEE COMMENT CARD BEFORE STATEMENT 1
      TABLE(MOVE)=TABLE(MOVE)+PARTM(IPM)*EXP(-XLAMDA*DEL)
      RETURN
C
C     AFTER PARTICLE IS MOVED DELP DAYS,
C     THIS SECTION TABULATES IN WHICH GRID THE
C     PARTICLE RESIDES
C
2     IX=XX+0.5
      IY=YY+0.5
      NPT(IX,IY)=NPT(IX,IY)+1
      PARTM(IPM)=PARTM(IPM)*EXP(-XLAMDA*DEL)
      IF(PARTM(IPM) .LT. 1E-30)PARTM(IPM)=0.
      XNPT(IX,IY)=XNPT(IX,IY)+PARTM(IPM)
      MOVE=0
      RETURN
      END
```

```
C
C     ********************************************
C     THIS SUBROUTINE CALCULATES VELOCITIES OF
C     PARTICLES BY DOUBLE INTERPOLATION
C     OF NODAL VELOCITIES, CHECKS BOUNDARIES
C     TO PROVIDE PROPER VELOCITY DETERMINATIONS, AND
C     TO KEEP PARTICLES INSIDE MODEL, AND
C     KEEPS VELOCITIES FROM CAUSING POSSIBLE
C     UNDERFLOWS.
C     ********************************************
C
      SUBROUTINE VELO(XX,YY,VX,VY)
      COMMON /VEL/NC,NR,ANC,ANR,V(30,48,2)
      LIJ(NR,J,Y)=MIN0(NR-1,MAX0(1,J+
     1IFIX(SIGN(1.0,Y-0.5))))
    1 I=XX
      J=YY
      IF(I.LE.0)I=1
      IF(I.GE.NC)I=NC-1
      IF(J.LE.0)J=1
      IF(J.GE.NR)J=NR-1
      X=XX-I
      Y=YY-J
      VX=Y*V(I,J+1,2)+(1.-Y)*V(I,J,2)
      VY=X*V(I+1,J,1)+(1.-X)*V(I,J,1)
      JY=LIJ(NR,J,Y)
      IX=LIJ(NC,I,X)
      IF(ABS(VY).LE.1E-30) GO TO 20
      IF(JY.EQ.J) GO TO 20
      YZ=ABS(Y-0.5)
      VY=VY*(1.0-YZ)+YZ*
     1(X*V(I+1,JY,1)+(1.0-X)*V(I,JY,1))
   20 IF(IX.EQ.I) GO TO 30
      IF(ABS(VX).LE.1E-30) GO TO 30
      XZ=ABS(X-0.5)
      VX=VX*(1.0-XZ)+XZ*
     1(Y*V(IX,J+1,2)+(1.0-Y)*V(IX,J,2))
   30 CONTINUE
      IF(ABS(VX).LE.1E-30)VX=1E-30
      IF(ABS(VY).LE.1E-30)VY=1E-30
      RETURN
      END
      SUBROUTINE MAP       74/74    OPT=1 ROUND=+-*/              FTN 4.6  460          78/12/27. 11.43.56          PAGE      1


        1          C
                   C       ***********************************************
                   C       THIS SUBROUTINE PRINTS THE NPART MATRIX
                   C       WHERE NUMBER OF PARTICLES ARE STORED.
        5          C       ***********************************************
                   C
                           SUBROUTINE MAP
                           COMMON/TRACE/NP,MAXP,PM,DISP,TRATIO,X(5001),
                          1Y(5001),MARK(30,48),TMAP
       10                  COMMON /FORMS/ TABLE(500),NPART(30,48)
                           COMMON/VEL/NC,NR
                           COMMON/DECAY/XNPT(30,48),XLAMDA,PARTM(5001)
                           PRINT 5
                   5       FORMAT(*1MAP SHOWING NUMBER OF PARTICLES*
       15                 1,* RESIDING IN MODEL GRIDS*)
                           PRINT 2,PM,NP,TMAP
                   2       FORMAT(* PM=*,E15.4,2X,*NP IN SYSTEM=*,
                          12X,I5,2X,*TMAP=*,G8.2,1X,*DAYS*)
                           DO 4 J=1,NR
       20                  PRINT 1,(NPART(I,J),I=1,NC)
                   1       FORMAT(9X,50I3)
                   4       CONTINUE
                           WRITE(6,3)(X(K),Y(K),PARTM(K),K=1,5)
                   3       FORMAT(3F9.3)
       25                  RETURN
                           END

  CARD NR. SEVERITY  DETAILS    DIAGNOSIS OF PROBLEM

       21     I       20 CD 21  FIELD WIDTH IS GREATER THAN 137 CHARACTERS.  IT MAY EXCEED THE I/O DEVICE CAPACITY.
       21     I       21 CD 21  TOTAL RECORD LENGTH IS GREATER THAN 137 CHARACTERS.  IT MAY EXCEED THE I/O DEVICE CAPACITY.
```

```
    1            SUBROUTINE MAP1
           C
           C    THIS IS A VEFSION OF MAP THAT SMOOTHS THE NPART MATRIX
           C     IN TIME
    5      C
                 INTEGER OLDNP1,OLDNP2
                 DIMENSION IPART(30,48),OLDNP1(30,48),OLDNP2(30,48)
                 COMMON/POL/X1,DX,Y1,DY,DELP
                 COMMON/TRACE/NP,MAXP,PM,DISP,TRATIO,X(5001),
   10           1Y(5001),MARK(30,48),TMAP
                 COMMON /FORMS/ TABLE(500),NPART(30,48)
                 COMMON/VEL/NC,NR
           C
                 IF(TMAP .GT. (2.*DELP))PRINT 5
   15      5     FORMAT(*1MAP SHOWING NUMBER OF PARTICLES*
                1,* RESIDING IN MODEL GRIDS*)
                 DO 10 I=1,NC
                     DO 15 J=1,NR
                            IPART(I,J)=(OLDNP2(I,J)+2*OLDNP1(I,J)+NPART(I,J))/4
   20                       OLDNP2(I,J)=OLDNP1(I,J)
                            OLDNP1(I,J)=NPART(I,J)
              15          CONTINUE
              10 CONTINUE
                 XTMAP=TMAP-DELP
   25            IF(TMAP .GT. (2.*DELP))PRINT 2,PM,NP,XTMAP
           2     FORMAT(* PM=*,E15.4,2X,*NP IN SYSTEM=*,
                12X,I5,2X,*TMAP=*,G8.2,1X,*DAYS*)
                 DO 4 J=1,NR
                     IF(TMAP .GT. (2.*DELP))PRINT 1,(IPART(I,J),I=1,NC)
   30      1     FORMAT(9X,50I3)
           4     CONTINUE
           C     PRINT 3,X(1),Y(1),X(2),Y(2),X(3),Y(3),X(4),Y(4),X(5),Y(5)
           3     FORMAT(2F9.3)
                 RETURN
   35            END

CARD NR. SEVERITY  DETAILS    DIAGNOSIS OF PROBLEM

    30       I      20 CD 30  FIELD WIDTH IS GREATER THAN 137 CHARACTERS.  IT MAY EXCEED THE I/O DEVICE CAPACITY.
    30       I      21 CD 30  TOTAL RECORD LENGTH IS GREATER THAN 137 CHARACTERS.  IT MAY EXCEED THE I/O DEVICE CAPACITY.
```

```
      C
      C        *********************************************
      C        THIS SUBROUTINE PRINTS THE NUMBER OF
      C        PARTICLES CAPTURED BY SINK DURING
      C        TIME INCREMENT DELP.
      C        *********************************************
      C
               SUBROUTINE SUMMRY
               COMMON /FORMS/ TABLE(500)
               DO 1 I=1,500
               IF(TABLE(I).GT.0.0)PRINT 2,I,TABLE(I)
      1        CONTINUF
      2        FORMAT(* SINK"*,I2,F10.4)
               RETURN
               END
```

```
FUNCTION ANORM       74/74   OPT=1 ROUND=+-*/             FTN 4.6  460          78/12/27. 11.43.56        PAGE      1

            C
            C     **********************************************
            C     THIS FUNCTION PRODUCES A RANDOM
            C     NUMBER BETWEEN -6 AND +6,
            C     FOLLOWS A NORMAL DISTRIBUTION, AND
            C     HAS A STANDARD DEVIATION OF 1 AND A
            C     MEAN OF ZERO.
            C     **********************************************
            C
                    FUNCTION ANORM(K)
                    ANORM=-6.0
                    DO 1 I=1,12
            1       ANORM=ANORM+RANF(0)
                    RETURN
                    END
```

```
C
C     ********************************************
C     THIS SUBROUTINE PRINTS OUT THE CONCENTRATION
C     OF THE WATER FLOWING INTO SINKS SO DESIGNATED
C     BY SPECIFYING A VALUE IN MARK(I,J).  TWO
C     TYPES OF SINKS ARE ALLOWED.  THE FIRST TYPE
C     IS A NODE THAT IS PUMPING (A VALUE IN THE
C     Q(I,J) ARRAY FOR THIS NODE EXISTS).  THE
C     SECOND TYPE IS A NODE THAT REPRESENTS
C     NON-PUMPED LINES OF DISCHARGE SUCH AS A
C     RIVER (A VALUE IN THE RECHARGE FACTOR
C     ARRAY R(I,J) EXISTS FOR THIS TYPE OF NODE).
C     ********************************************
C
      SUBROUTINE SNKCON
      COMMON/SINK/CONSNK(30,48)
      COMMON/EXTRA2/CH(30,48),HO(30,48),G(30),
     1B(30),R(30,48),TIME,E
      COMMON/VEL/NC,NR
      COMMON/TRACE/NP,MAXP,PM,DISP,TRATIO,X(5001),
     1Y(5001),MARK(30,48)
      COMMON/AQUI/H(30,48),RH(30,48),DELTA,Q(30,48)
      COMMON/FORMS/TABLE(500)
      COMMON/POL/X1,DX,Y1,DY,DELP
      DO 5 I=1,NC
      DO 5 J=1,NR
      CONSNK(I,J)=0.0
5     CONTINUE
      DO 1 I=1,NC
      DO 1 J=1,NR
      IF(MARK(I,J).LT.1)GO TO 1
      MOVE=MARK(I,J)
      IF(TABLE(MOVE).EQ.0)GO TO 1
      IF(Q(I,J).GT.0.0)GO TO 2
      IF(R(I,J).EQ.0.)GO TO 1
      IF((H(I,J)-RH(I,J)).EQ.0.0)GO TO 1
      PRINT 6 ,TABLE(MOVE),PM,H(I,J),RH(I,J),DELP,R(I,J)
6     FORMAT(6E10.4)
      CONSNK(I,J)=TABLE(MOVE)*PM*1E6/((H(I,J)-
     1RH(I,J))*DELP*R(I,J)*8.3453)
      GO TO 4
2     CONSNK(I,J)=TABLE(MOVE)*PM*1E6/
     1((Q(I,J)*DELP*8.3453))
4     CONTINUE
      IF(TABLE(MOVE).GT.0.0)PRINT 3,I,J,CONSNK(I,J)
3     FORMAT(/* SINK COORDINATES*,2I3,2X,F10.4)
1     CONTINUE
      RETURN
      END
```

```
C
C     ********************************************
C     THIS SUBROUTINE CONVERTS NPART
C     TO A CONCENTRATION MAP
C     ********************************************
C
      SUBROUTINE CONMAP
      INTEGER OUT
      DIMENSION CONC(30,48),UCONC(30,48)
      COMMON/SINK/CONSNK(30,48)
      COMMON/AQUI2/RD(30,48),BOT(30,48)
      COMMON/AQUI/H(30,48),RH(30,48),DELTA,Q(30,48)
      COMMON/VEL/NC,NR
      COMMON/FORMS/TABLE(500),NPART(30,48)
      COMMON/POR/APOR,EPOR,CONSOR(30,48)
      COMMON/VAR/DELX(50),DELY(50)
      COMMON/EXTRA2/CH(30,48)
      COMMON/TRACE/NP,MAXP,PM,DISP,TRATIO,X(5001),Y(5001),MARK(30,48)
      COMMON/CONTRL/XL1,YL1,TL1
      COMMON/DECAY/XNPT(30,48),XLAMDA,PARTM(5001)
      DO 4 I=1,NC
      DO 4 J=1,NR
      CONC(I,J)=0.0
4     CONTINUE
C   SETUP TAPE7 AS OUTPUT CONCENTRATION FILE
      DO 1 I=1,NC
      DO 1 J=1,NR
      UCONC(I,J)=PM*1E6/(APOR*(AMIN1(H(I,J),CH(I,J))-BOT(I,J))*
     1(DELY(J)*DELX(I))*62.4)
      CONC(I,J)=XNPT(I,J)*PM*1E6/(APOR*(AMIN1(H(I,J),
     1CH(I,J))-BOT(I,J))*(DELX(I)*DELY(J))*62.4)
C
C  INSERT THE SINK AND SOURCE CONCENTRATIONS INTO THE CONC ARRAY
C
      IF(TL1 .EQ. -10.)GO TO 1
      IF(MARK(I,J) .NE. 0)CONC(I,J)=CONSNK(I,J)
      IF(CONSOR(I,J) .NE. 0.)CONC(I,J)=CONSOR(I,J)
    1 CONTINUE
      WRITE(7,1001)NC,NR,(DELX(K),K=1,NC),(DELY(K),K=1,NR)
 1001 FORMAT(2I5,(10E10.3))
      DO 2 J=1,NR
      WRITE(6,3)J,(CONC(I,J),I=1,NC)
2     WRITE(7,3)J,(CONC(I,J),UCONC(I,J),I=1,NC)
3     FORMAT(I5,(10E10.3))
      RETURN
      END
```

APPENDIX J - SURFACE WATER BIBLIOGRAPHY

Arnold, F.B., and Dollhopf, D.J.
1977
Soil Water & Solute Movement in Montana Strip Mine Spoils
Research Report #106, Montana Agricultural Experiment
Station, Montana State University, Bozeman, Montana

A study was initiated in November, 1974, at the Peabody Big Sky Mine near Colstrip, Montana to determine soil water and solute movement in strip mine spoils. Three spoils treatments, consisting of topsoiled non-vegetated, topsoiled revegetated and nontopsoiled re-vegetated spoils, and a native range site were studied. Neutron probes were used to study in situ soil water budgets. The quantities of soil water movement in the native range was approximately 1.5 times greater than in spoils. Spoils were found to have higher clay and silt contents, higher bulk densities, and lower infiltration rates. No definite trends in solute movement were found. This report is the first of a continuing study.

Bren, L.J., and Turner, A.K.
1978
"Wave Propagation in Steep Rough Mountain Streams"
ASCE, Journal of the Hydraulics Division
Vol. 104, No. HY5, p. 745-754

Using a defined reach of steep, rough, natural channel the parameters of kinematic wave theory were measured directly. Kinematic wave theory was found to give a good simulation of the hydrograph recession and to reproduce the features of the rising hydrograph.

Culler, R.C., Hadley, R.F., Schumm, S.A.
1961
Hydrology of the Upper Cheyenne River Basin
U.S. Geological Survey Water Supply Paper 1531

This paper is divided into two parts. Part A, by Culler, discusses the hydrology of stock-water reservoirs. Part B, by Hadley and Schumm, discusses erosion and sedimentation. The objective of Part A was to determine the effect on runoff of the many stock reservoirs in the Cheyenne River Basin above Angostura Dam (about 40 miles downstream of the boundary of the structural Powder River Basin). A random sampling procedure was used to estimate the total reservoir volume in the study area. Approximately 50 reservoirs were monitored for stage each summer for four years. Evaporation and seepage estimates were made for some of the reservoirs. Good correlation was found between reservoir evaporation and Class A pan evaporation.

Cunningham, A.B.
1977
Modeling and Analysis of Hydraulic Interchange of Surface and Groundwater
Technical Report Series H-W, Hydrology and Water Resources Publication No. 34, Water Resources Center, Desert Research Institute, University of Nevada

A technique for modeling the hydraulic interchange between surface and groundwater in an unconfined aquifer-river system has been developed. Modeling procedure consists of simultaneous solution of the Saint Venant equations for one dimensional open channel flow, and the Boussinesq equation of two-dimensional, transient groundwater flow. Galerkin finite element technique was used for model solution. The model was tested for both a hypothetical case and the lower Truckee River in Nevada. A sensitivity analysis showed that Manning's n, channel slope, and stream-aquifer interchange were the most sensitive input parameters. Good agreement between predicted and observed parameters was found for most of the Truckee River model. The hypothetical cases in this report could serve as a valuable source of data on which to verify a similar model.

Donigan, A.S., Beyerlein, D.C., Davis, H.H., and Crawford, N.H., Hydrocomp Inc.
1977
Agriculture Runoff Management (ARM) Model Version II: Refinement and Testing
EPA-600/3-77-098, Ecological Research Series, Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Athens, Georgia

The Agriculture Runoff Management (ARM) Model simulates hydrology, sediment production, and pesticide and nutrient processes in small agricultural watersheds. The primary functions of the ARM model are to determine the quantity and quality of runoff, particularly the fate of pesticides and nutrients applied to the soil during agricultural production.

Hydrologic simulation accounts for surface runoff, interflow, groundwater flow, and soil moisture storage. The soil profile is divided into three zones. The zones are set up mainly to aid in the pesticide and nutrient simulation process.

Each zone has its own storage capacity which is derived mainly through the model calibration process. Evapotranspiration is calculated using a monthly index based on areal density of vegetation. Snowmelt and accumulation are calculated by using an energy balance approach utilizing the inputs of wind, solar radiation, temperature, and humidity. It should be noted that since the ARM model is designed to simulate pesticide, nutrient, and sediment processes as well as hydrology, it doesn't necessarily take the most desirable route for evaluating hydrology alone.

Refinements to the model are the result of testing done on two small agricultural watersheds. Data from the study watersheds in Watkinsville, Georgia and East Lansing, Michigan were compared with the computed results of the model. Although further testing is needed, the ARM model can provide good simulation of the hydrology of small agricultural watersheds.

Donigan, A.S., Davis, H.H., Hydrocomp Inc.
1978
User's Manual for Agricultural Runoff Management (ARM) Model
EPA-600/3-78-080, Environmental Research Laboratory, U.S. Environmental Protection Agency, Athens, Georgia

The ARM User's Manual provides complete instructions for the use of the Agricultural Runoff Management Model, Versions I and II. Its main function is to assist the user by providing detailed instructions, guidelines, and information helpful in the evaluation of parameters, calibration, operation, and application of the ARM model. Included in the manual are descriptions of the model structure, components, operation and computer requirements.

Model execution data, parameter evaluation data, and calibration and verification data are each given a detailed discussion. Sources of data are given and guidelines for parameter evaluation are presented. Instructions for model calibration procedures are given in detail. Sample input and output sequences, as well as tables describing the format of input/output information, are also included.

Engman, E.T., and Rogowski, A.S.
1974
"A Partial Area Model for Storm Flow Synthesis"
Water Resources Research
Vol. 10, No. 3, p. 464-472

A computer hydrologic simulation model was written based on the partial contributing area concept. It utilizes the Phillips infiltration equation for computation of rainfall excess, and it incorporates two stages of kinematic routing. In the first stage, the rainfall excess is routed over a flow plane to become the lateral inflow hydrograph for the second or channel phase. The overland flow plane expands upslope as the infiltration capacity is exceeded, the size of contributing area and the length of the flow plane being computed from infiltration curves.

The model was tested on a 144 acre watershed and an excellent simulation obtained. The model is notable for its lack of an interflow component. This model is the state of the art for small watershed modeling, although it may have difficulty on larger watersheds. The partial area concept is one of the more valid concepts in hydrology today.

Frickel, D.G., and Shown, L.M.
1974
Map Showing Streamflow Volumes in Northeastern Wyoming and Southeastern Montana
U.S. Geological Survey, Miscellaneous Investigations Series, Map I-847-B

The average annual volume of flow and the 10-year annual minimum volume are shown for the streams in the Powder River Basin. The locations of gaging stations and whether a stream is perennial or ephemeral is also shown.

Holtan, H.N., Stiltner, G.H., Henson, W.H., and Lopez, N.C.
1975
USDAHL-74 Revised Model of Watershed Hydrology
Technical Bulletin No. 1518, Agricultural Research Service, U.S. Department of Agriculture, Washington, D.C.

The Agricultural Research Service (ARS) USDAHL-74 Model of Watershed Hydrology simulates the processes involved in the hydrology of small agricultural watersheds. It is designed to serve the purposes of agricultural watershed engineering. Parameters for hydrologic grouping of soils, land use, evapotranspiration, infiltration, flow routing, and hydrogeology are given detailed descriptions on how they are determined and how they are used by the model. The ARS model pays close attention to the influences of crop production and land use on watershed hydrology. Of special note is a growth index for computing evapotranspiration. It uses daily temperature data and the cardinal temperatures for each crop to determine daily evapotranspiration potential. Also of note is the use of an equation developed by Grossman et al which determines the percent of soil cracking in the upper soil zones. Samples of input parameters and model output are included in the bulletin as well as detailed descriptions.

Snowmelt is calculated by an equation that takes into account only temperature and amount of vegetative cover. This may explain the relatively poor correlation between measured data and that computed by the model for the winter months. However, the overall results show good correlation between computed data and the data measured from the four test watersheds.

Huang, Y.H.
1978
"Channel Routing by Finite Difference Method"
ASCE, Journal of the Hydraulics Division
Vol. 104, No. HY10, p. 1379-1393

A kinematic finite difference method was developed for channel routing. The model was designed for use with hydrologic simulation models. Both linear and nonlinear procedures were developed and tested. Linear kinematic routing involves solution to the equation

$$Q = aA^m$$

where a and m are constants. Nonlinear routing involves a and m values that are functions of channel area. A method is also presented for determining the routing coefficients from topographic maps; a and m are estimated assuming a wide, shallow triangular channel. The study also showed that linear routing is unconditionally stable, and yields good results for small time increments. Nonlinear routing is only superior for larger time increments.

Klaveren, R.W.
1975
Estimating Evapotranspiration in the North Platte Basin of Wyoming
M.S. Thesis, University of Wyoming, Laramie, Wyoming

Methods of calculating potential evapotranspiration were compared and estimates of phreatophyte water use were made for the North Platte River Basin of Wyoming. Three methods of estimating potential evapotranspiration, the Jensen-Haise, Thornthwaite, and Blaney-Criddle, were evaluated and compared to adjusted pan evaporation. By a simple modification of the Thornthwaite equation, the most favorable correlation of potential evapotranspiration to pan evaporation was found. ET in the North Platte was estimated using the Blaney-Criddle method. Little or no data on phreatophyte root depths, water consumption, etc. is included in this report.

Knapp, R.M., Green, D.W., Pogge, E.C., Stanford, C.
1975
"Development and Field Testing of a Basin Hydrology Simulator"
Water Resources Research
Vol. 11, No. 6, p. 879-888

A computer model consisting of both surface water and groundwater was developed. Only influent streams are considered; there is no feedback from aquifer to stream. Input to the model includes precipitation, climatic conditions, boundary and initial conditions, and basin constants. The model was applied to the Little Arkansas River Basin of south central Kansas. A 25 year hydrologic history was simulated. Good agreement between model and field data was found for both surface and groundwater.

Konikow, L.F., and Bredehoeft, J.D.
1974
"Modeling Flow and Chemical Quality Changes in an Irrigated Stream-Aquifer System"
Water Resources Research
Vol. 10, No. 3, p. 546-561

A computer model was developed to predict changes in dissolved solids concentrations in the Arkansas River valley of southeastern Colorado. A finite difference groundwater model with an effluent stream were used to simulate flows. A groundwater quality model using the particle in a cell method was used to simulate total dissolved solids. A large amount of data was collected and excellent agreement between model and field data was found. The excellent agreement between model and field for groundwater quality is unusual in projects of this type. This project is somewhat similar in both technique and scale to the Powder River Basin study.

HITTMAN

Larson, L.W.
1971
Precipitation and Its Measurement, A State of the Art
Water Resources Series No. 24, Wyoming Water Resources
Research Institute, Laramie, Wyoming

A comprehensive review of the literature since 1966 for studies and articles dealing with precipitation and its measurement. Topics discussed include gages, gage comparisons, gage shields, errors in measurements, precipitation data, data analysis, networks, and electronic measurements for rain and snow. An annotated bibliography is included.

Lettau, H.
1969
"Evapotranspiration Climatonomy, I. A New Approach to
Numerical Prediction of Monthly Evapotranspiration, Runoff, and Soil Moisture Storage"
Monthly Weather Review
Vol. 97, No. 10, p. 691-699

A theoretical method to solve the water balance equation for land areas is discussed. By calculating water and energy balances using an empirical dryness ratio, and the Bowen ratio, both annual changes in runoff, or soil moisture can be computed. The method has some potential for calculation of net recharge to a large basin given accurate values of total surface runoff and precipitation.

Pinder, G.F., and Sauer, S.P.
1971
"Numerical Simulation of Flood Wave Modification Due to
Bank Storage Effects"
Water Resources Research
Vol. 7, No. 1, p. 63-69

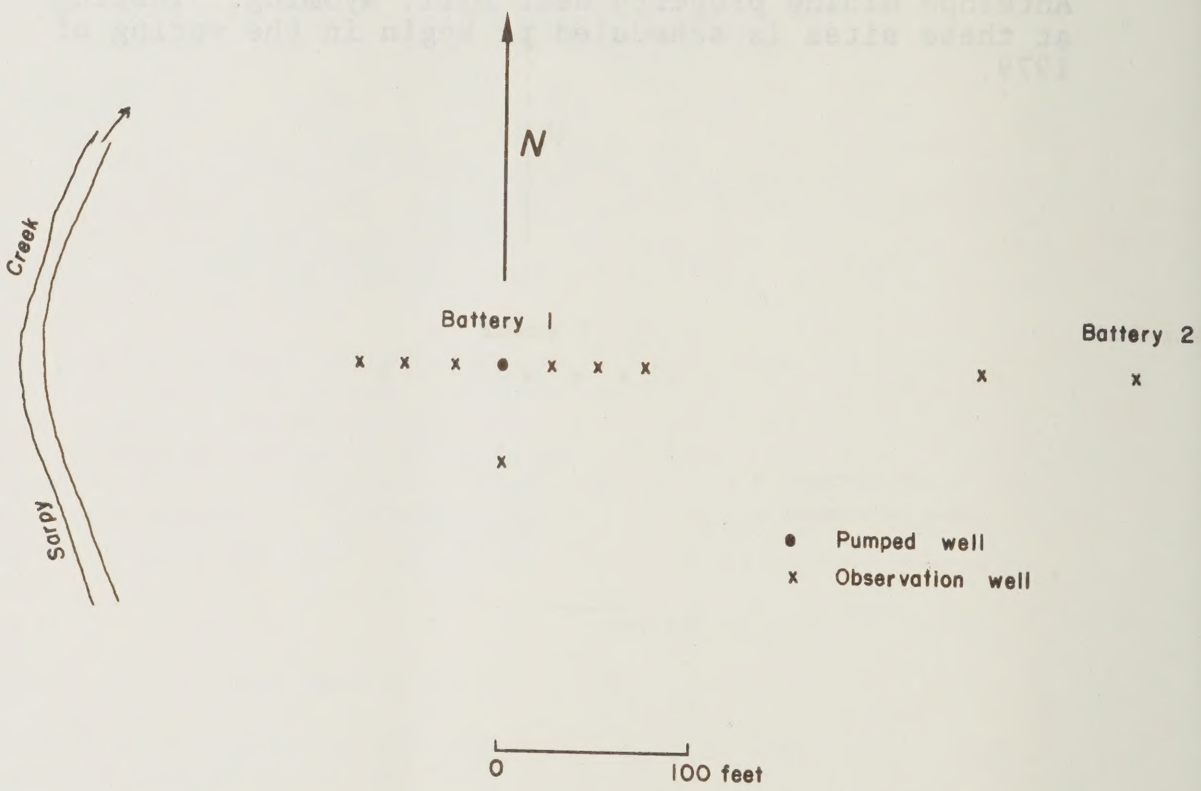
A two-dimensional, finite difference model of groundwater flow was coupled with a dynamic one-dimensional flow model. The models were allowed to iterate to steady state each time step. These models were used to simulate the modification of a flood wave due to bank storage. Numerical experiments indicate that flood waves may be modified considerably by bank storage, particularly in the lower segments of a long reach, and that the degree of modification is influenced markedly by the hydraulic conductivity of the aquifer. In general, two to five iterations were necessary to achieve stability between groundwater inflow and stream bed outflow each time step.

Ponce, V.M., Li, R., Simons, D.B.
1978
"Applicability of Kinematic and Diffusion Models"
ASCE, Journal of the Hydraulics Division
Vol. 104, No. HY3, p. 353-360

The kinematic and diffusion wave models have found application in engineering practice. The diffusion model assumes that inertia terms in the equation of motion (Saint Venant equations) are negligible as compared with the pressure, friction, and gravity terms. The kinematic model assumes that inertia and pressure terms are negligible as compared with the friction and gravity terms. The kinematic model was found to be applicable to problems involving steep bed slopes or long wave periods. The diffusion model is applicable to a wider variety of problems.

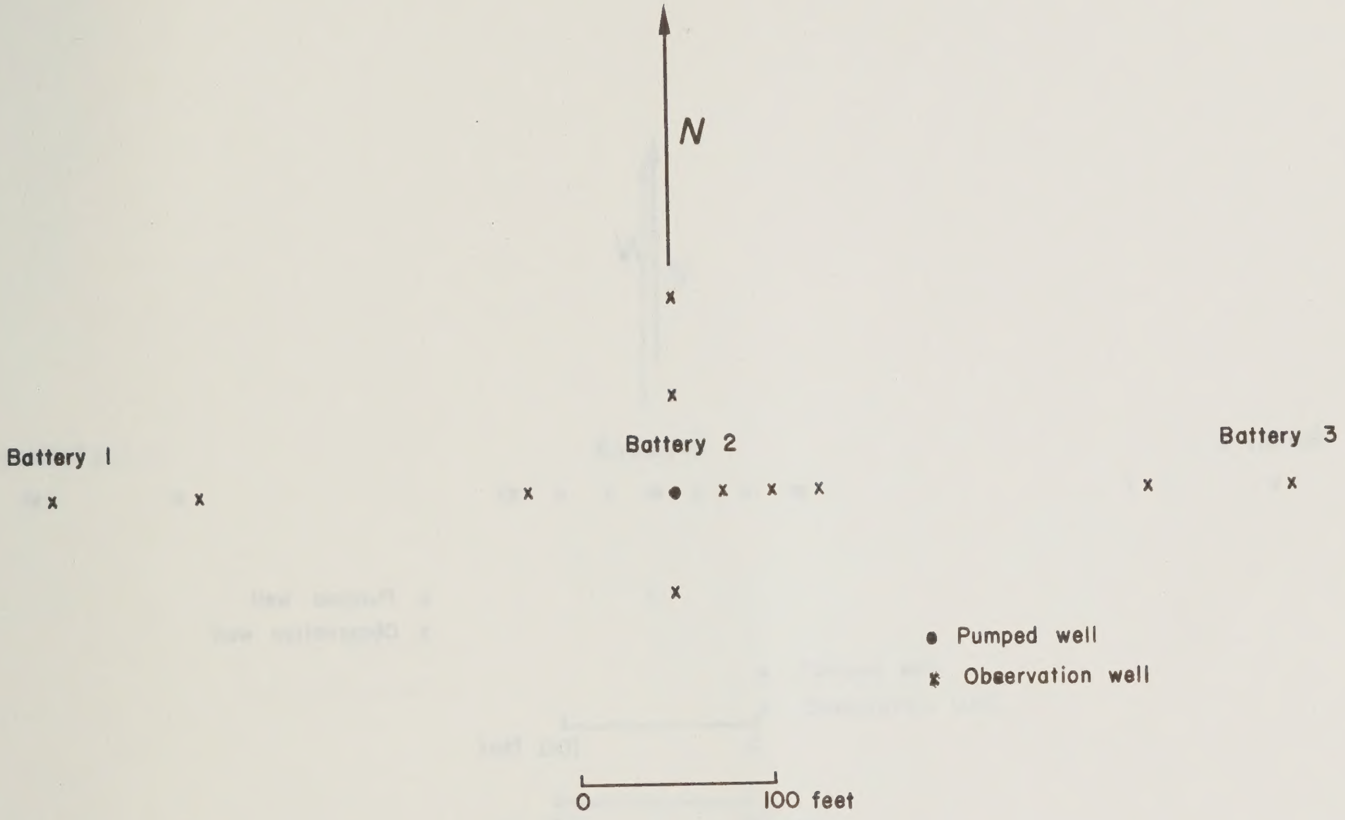
APPENDIX K - ADDITIONAL PUMPING TEST SITES

Contained herein are plan views of the seven alluvial aquifer pumping test sites on Westmoreland Resources' Sarpy Creek mine near Hardin, Montana. Also included is a geologic block diagram of the bedrock pumping test site on Peabody Coal Company's North Antelope mining property near Bill, Wyoming. Testing at these sites is scheduled to begin in the spring of 1979.


N
Creek
Sarpy
Battery 1
Battery 2
● Pumped well
x Observation well
0
100 feet

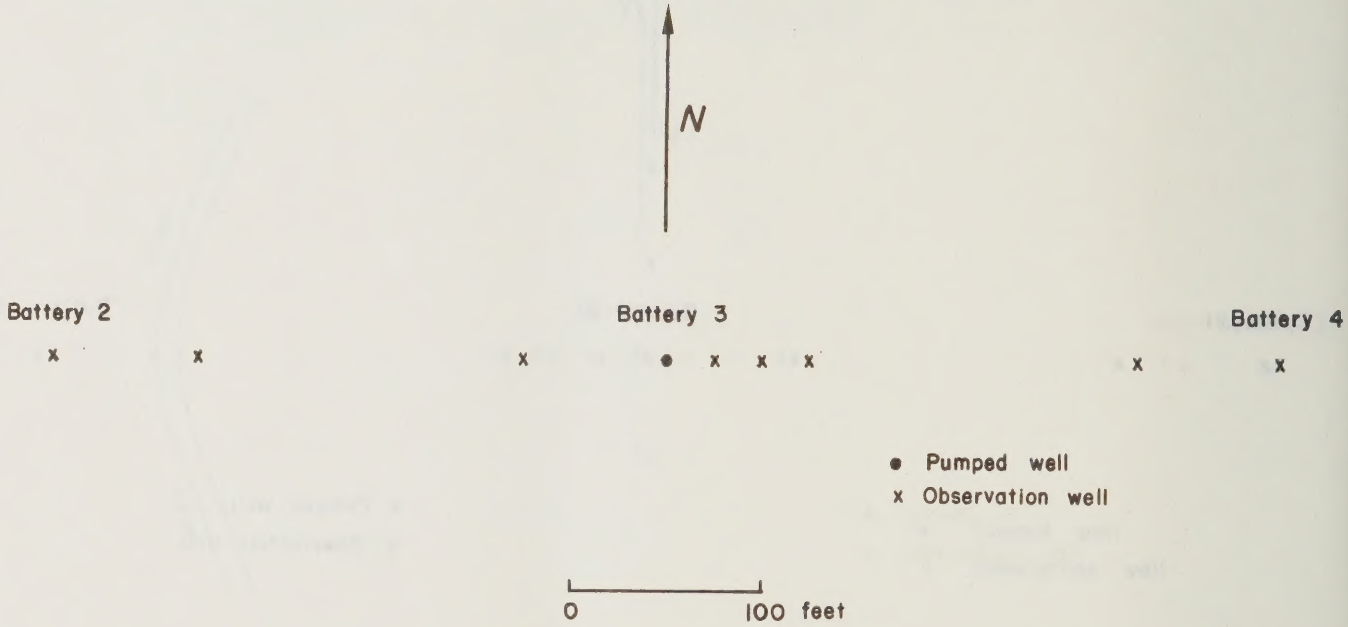
Well Configuration for Battery 1 Pump Test

Figure K-1. Plan View of Alluvial Aquifer Test Site No. 1


N
Battery 1
Battery 2
Battery 3
● Pumped well
x Observation well
0
100 feet

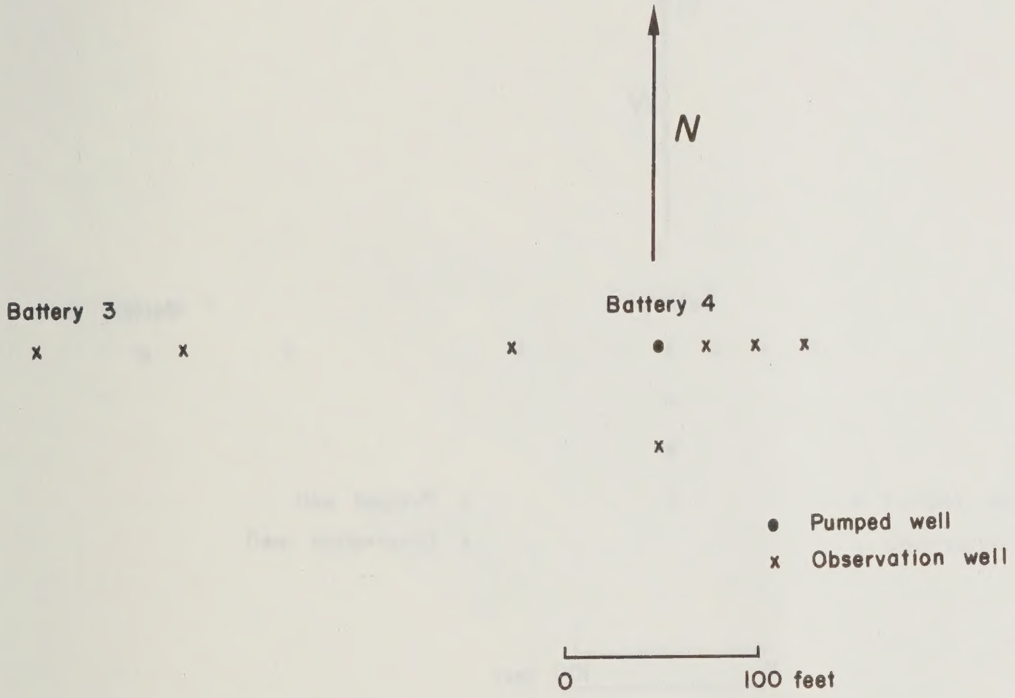
Well Configuration for Battery 2 Pump Test

Figure K-2. Plan View of Alluvial Aquifer Test Site No. 2


N
Battery 2
Battery 3
Battery 4
x
● Pumped well
x Observation well
0
100 feet

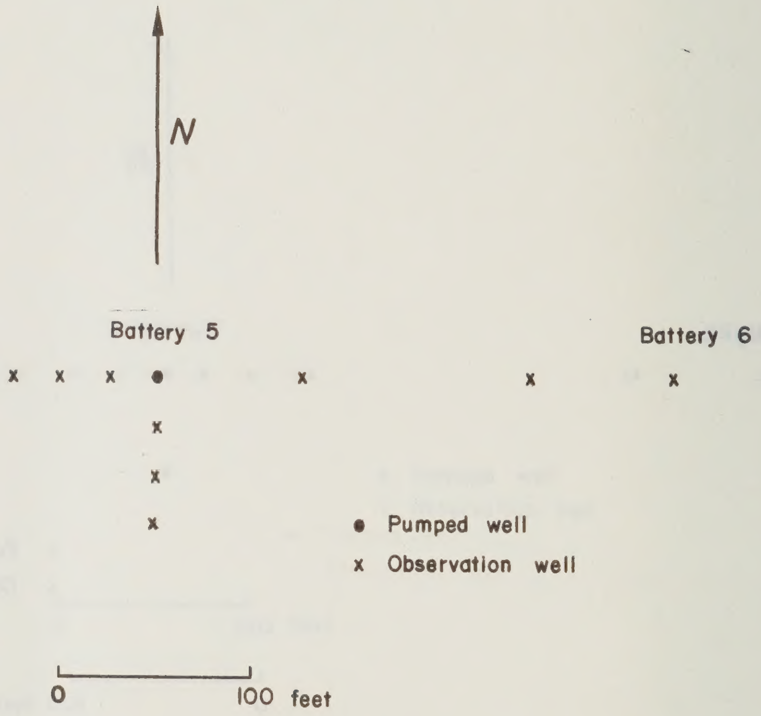
Well Configuration for Battery 3 Pump Test

Figure K-3. Plan View of Alluvial Aquifer Test Site No. 3


N
Battery 3
Battery 4
● Pumped well
x Observation well
0
100 feet

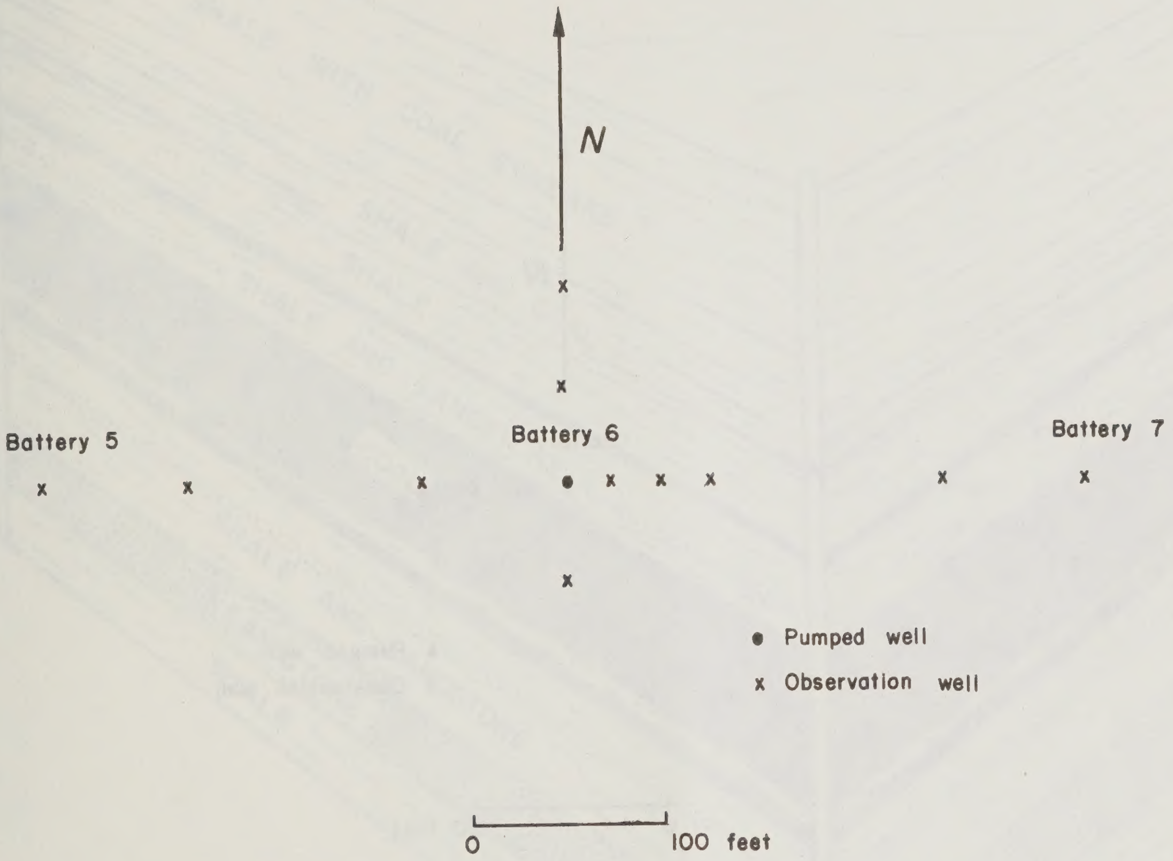
Well Configuration for Battery 4 Pump Test

Figure K-4. Plan View of Alluvial Aquifer Test Site No. 4


N
Battery 5
Battery 6
● Pumped well
x Observation well
0
100 feet

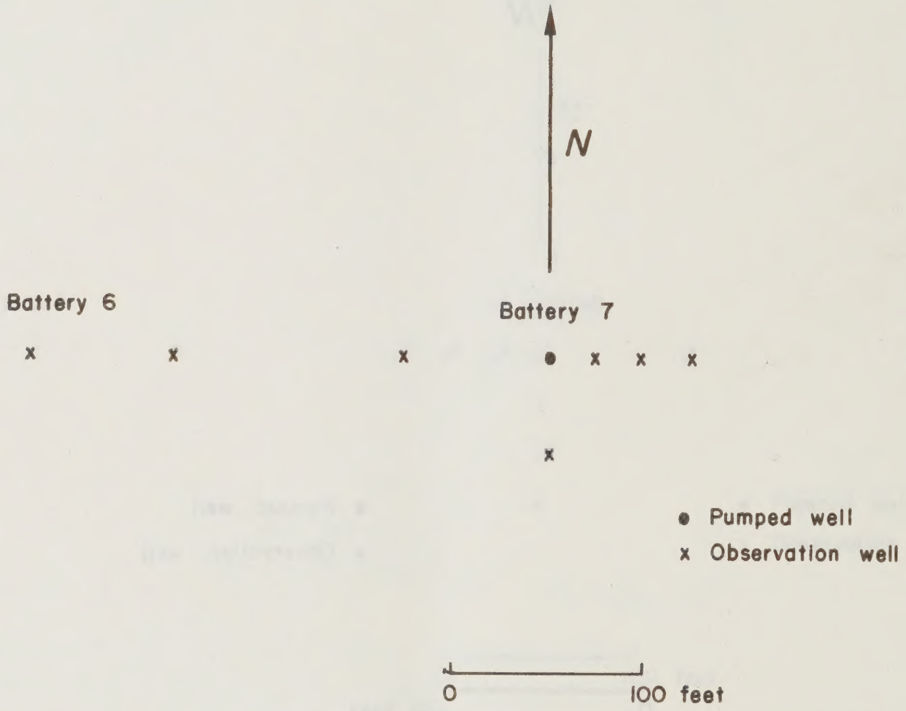
Well Configuration for Battery 5 Pump Test

Figure K-5. Plan View of Alluvial Aquifer Test Site No. 5


N
Battery 5
Battery 6
Battery 7
● Pumped well
x Observation well
0
100 feet

Well Configuration for Battery 6 Pump Test

Figure K-6. Plan View of Alluvial Aquifer Test Site No. 6


N
Battery 6
Battery 7
● Pumped well
x Observation well
0
100 feet

Well Configuration for Battery 7 Pump Test

Figure K-7. Plan View of Alluvial Aquifer Test Site No. 7

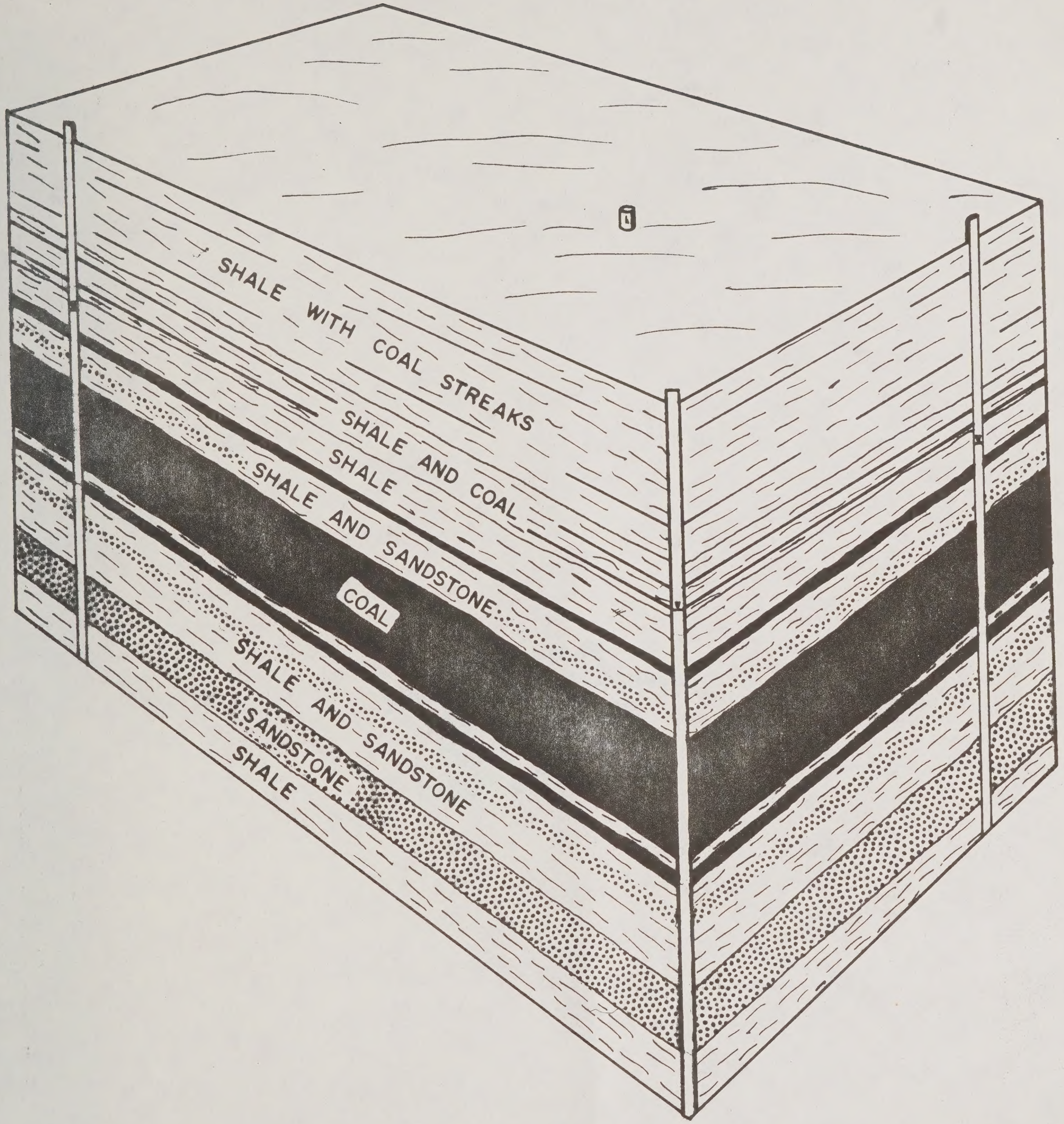

SHALE WITH COAL STREAKS
SHALE AND COAL
SHALE
SHALE AND SANDSTONE
COAL
SHALE AND SANDSTONE
SANDSTONE
SHALE

Figure K-8. Geologic Block Diagram of North Antelope Pumping Test Site